Observational Signatures of Magnetic Reconnection in the Extended Corona

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….. and First Results from the Hi-C II Sounding Rocket

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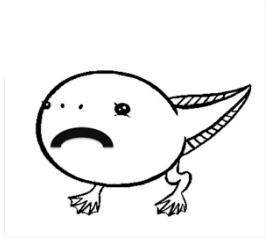
*Considerable contributions from K. Reeves & D. McKenzie

Supra-Arcade Downflows (SADs) Observations



Sadpoles, not tadpoles

Fig 1

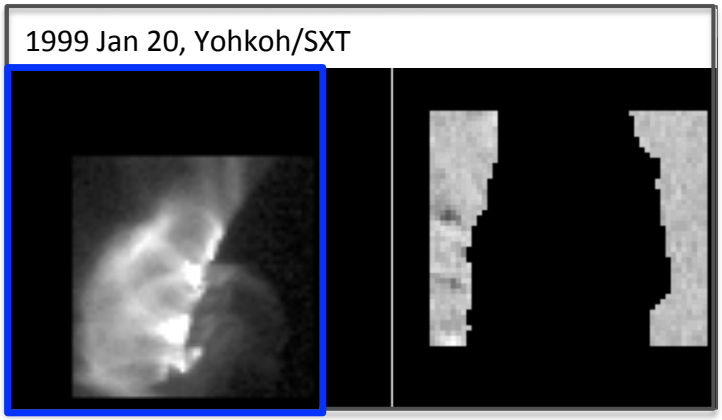


Fig 2

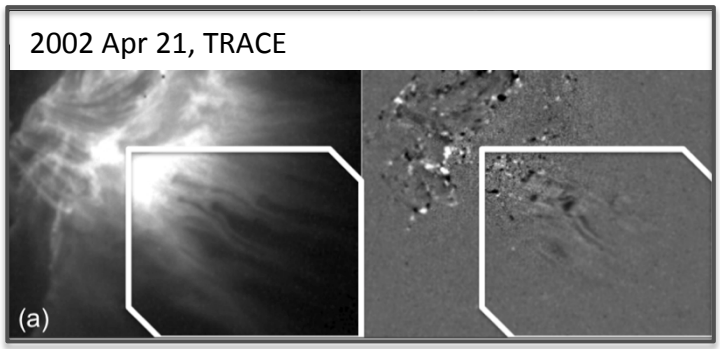


Fig 3

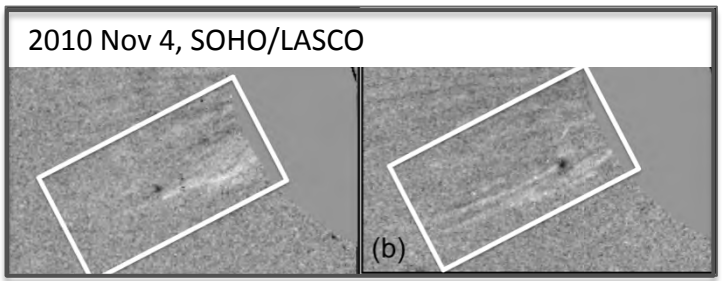
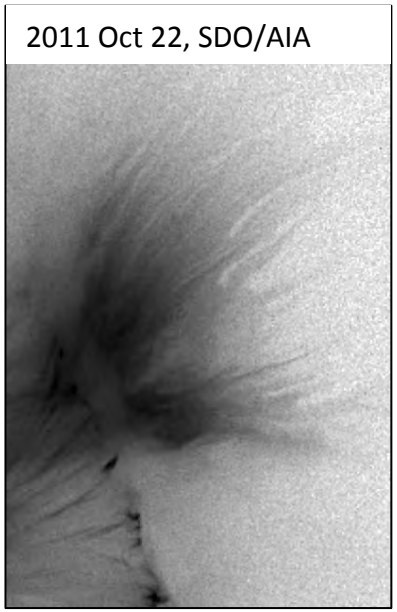


Fig 4



- Teardrop-shaped voids observed to travel sunward through the bright, hot fan extending outward along the spine of developing post-flare arcades.
- Observed with high-temperature instrumentation (EUV, X-ray) & white-light coronagraph (density)
- **LONG DURATION EVENTS**

Fig 5

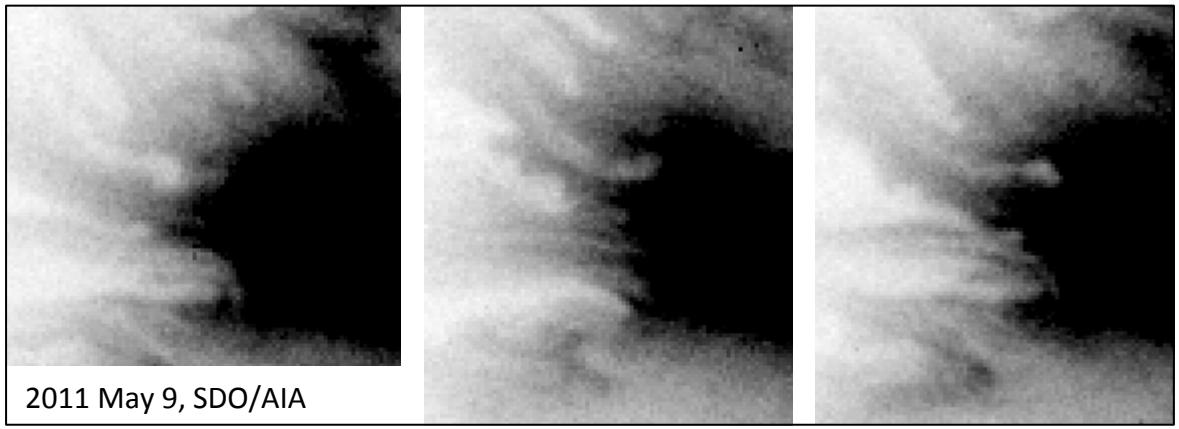


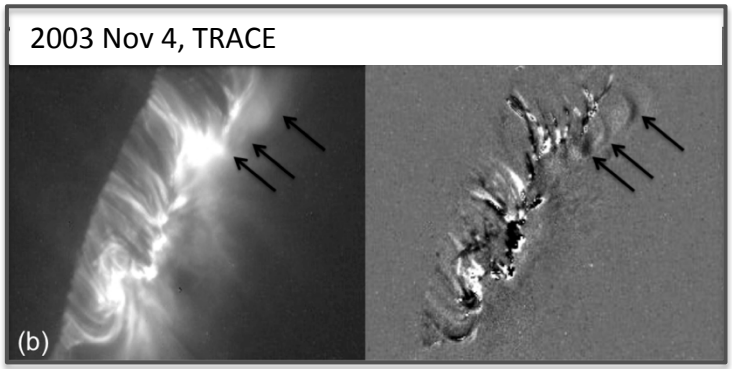
Fig 1: McKenzie & Savage 2009

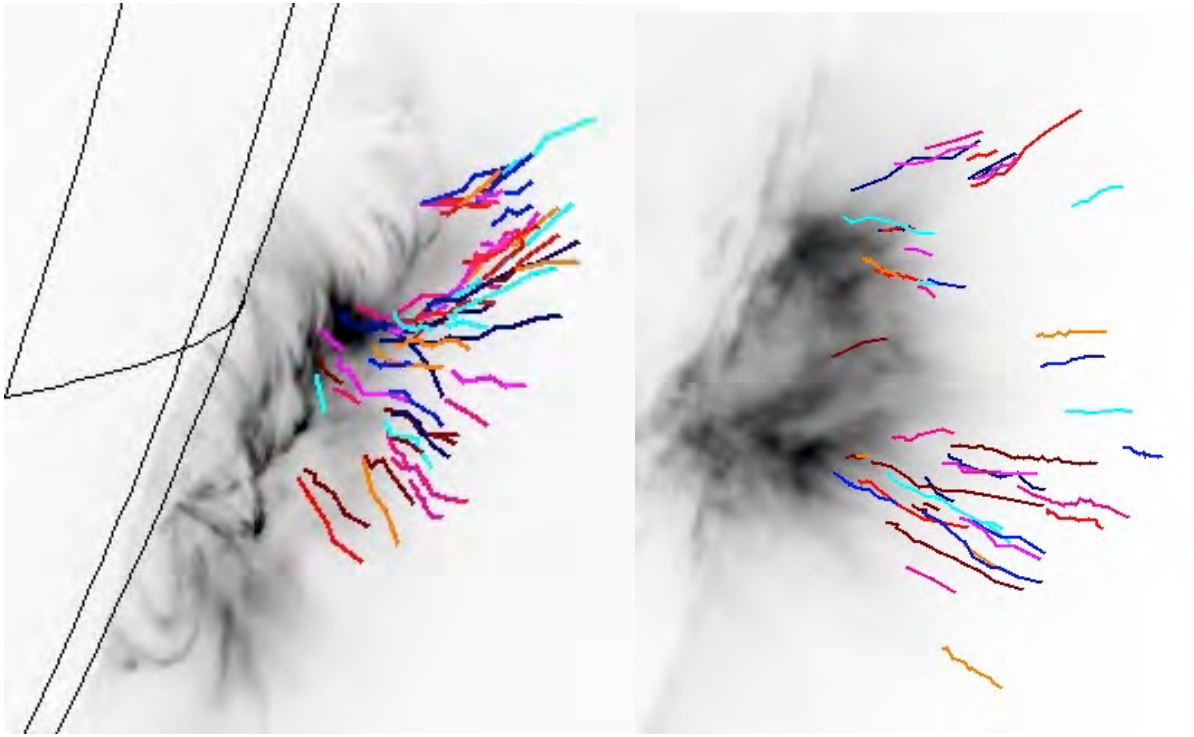
Fig 2: Savage et al. 2011

Fig 3: Savage et al. 2012

Supra-Arcade Downflowing Loops (SADLs) Observations

Fig 1





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Supra-Arcade Downflowing Loops (SADLs) Observations

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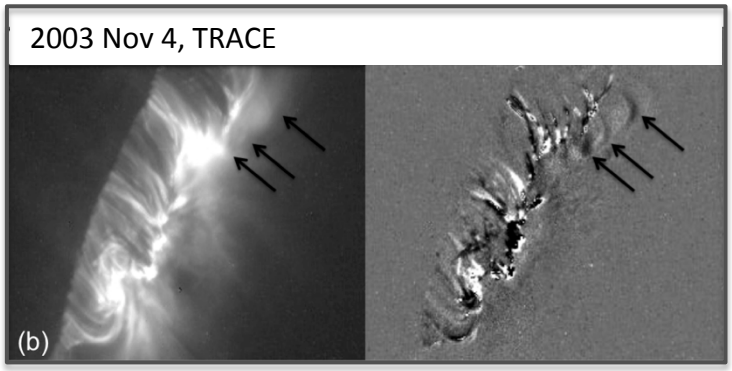
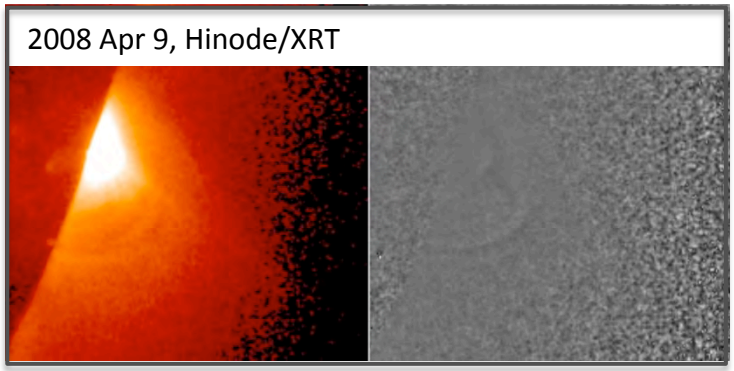
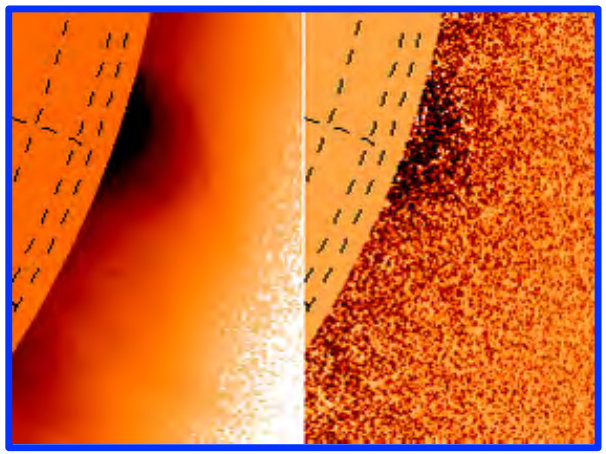


Fig 2





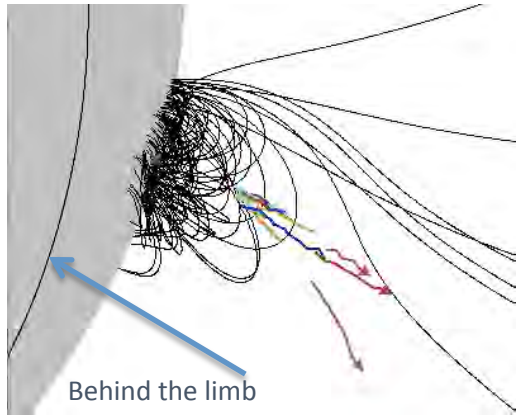


Fig 1: Savage & McKenzie 2011

Fig 2: Savage et al. 2010

Supra-Arcade Downflowing Loops (SADLs) Observations

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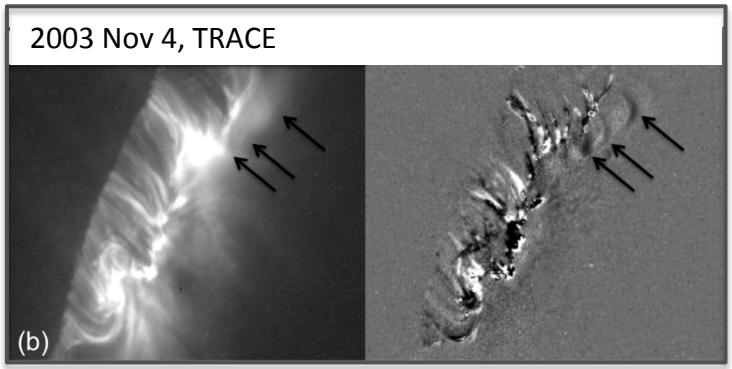

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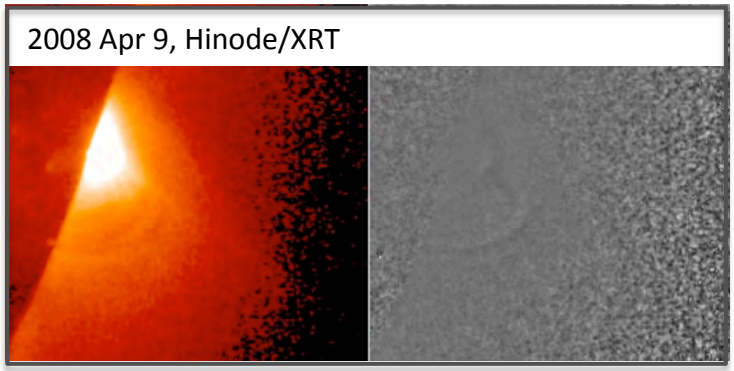
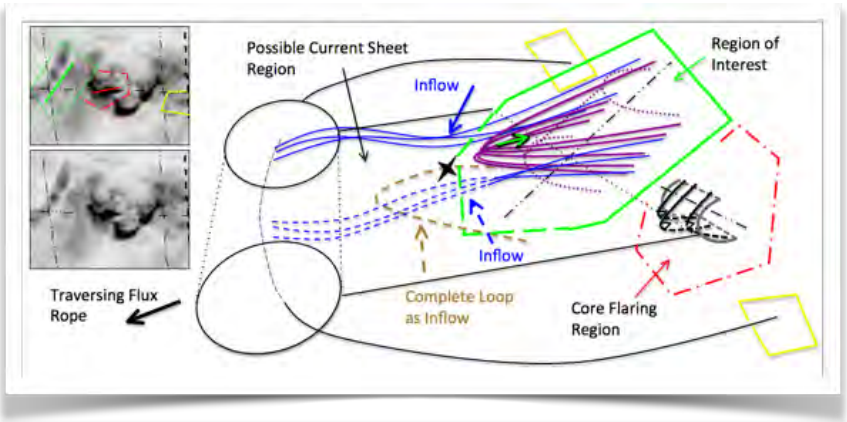
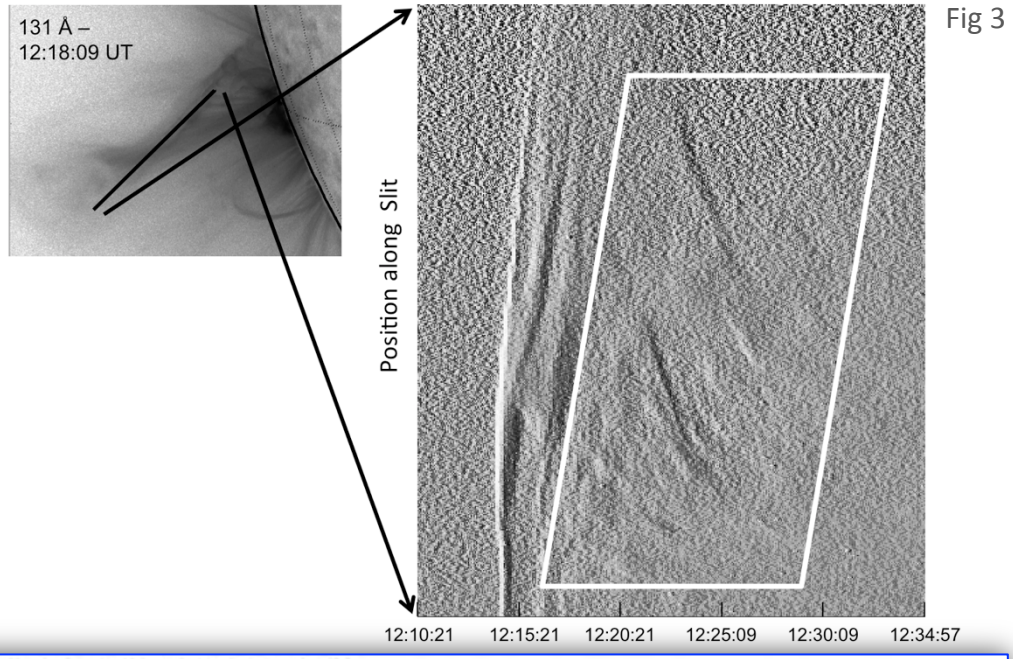




2010 Nov 3, SDO/AIA

Fig 3



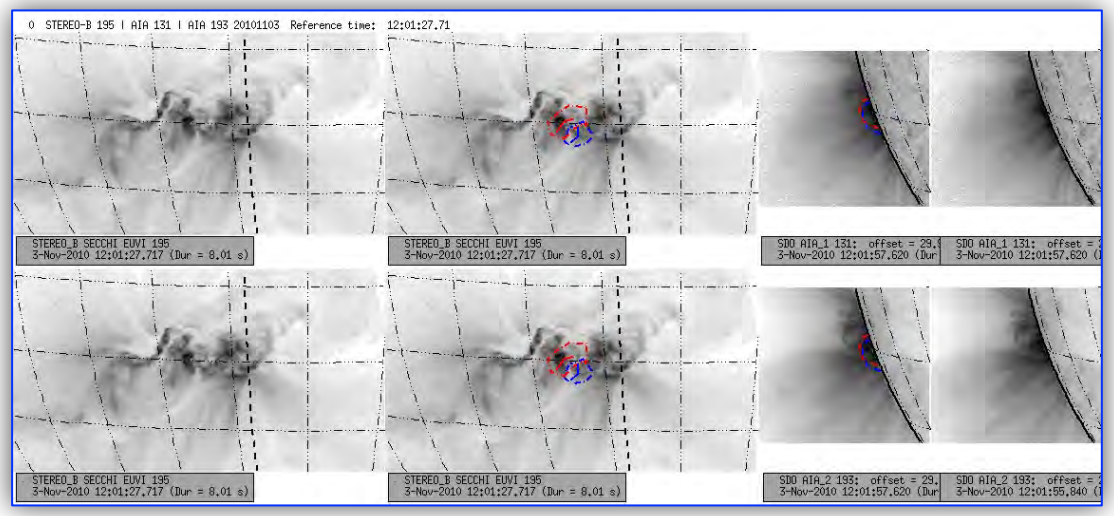


Fig 1: Savage & McKenzie 2011

Fig 2: Savage et al. 2010

Fig 3: Savage et al. 2012

Different from Plasmoid Observations

- Coherent 'bubble' of emitting plasma held together by magnetic fields.
- Observed with broadband-temperature instrumentation (EUV, X-ray, Hard X-ray) & white-light coronagraph (density)

➢ **Magnetic Islands**

Fig 1

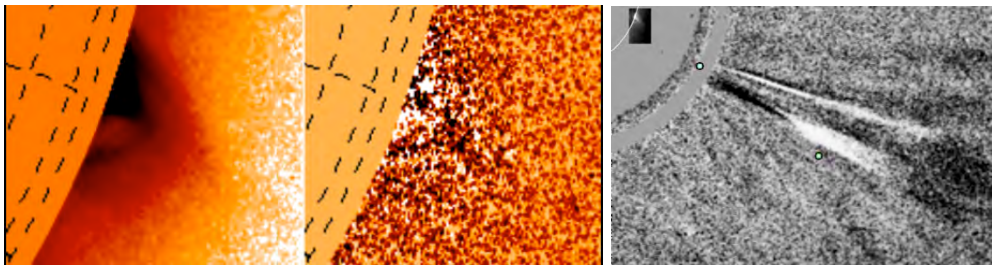
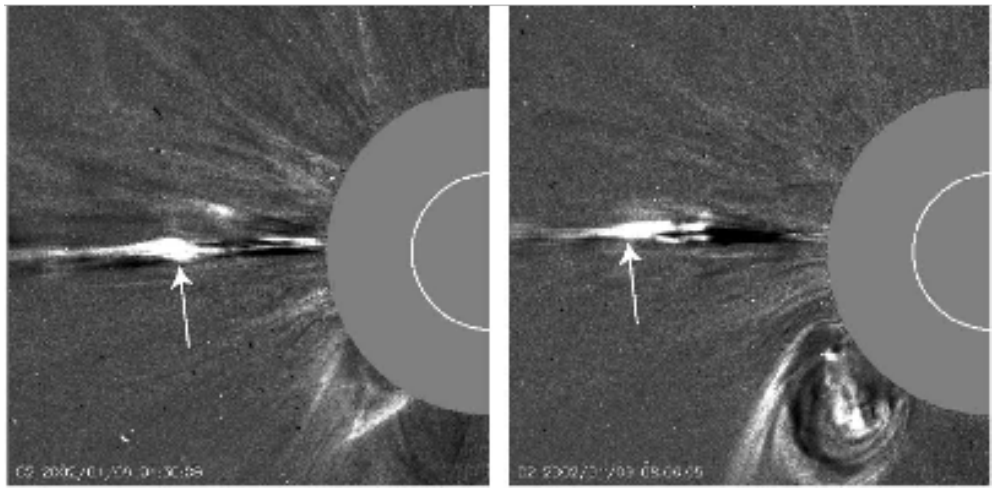


Fig 2



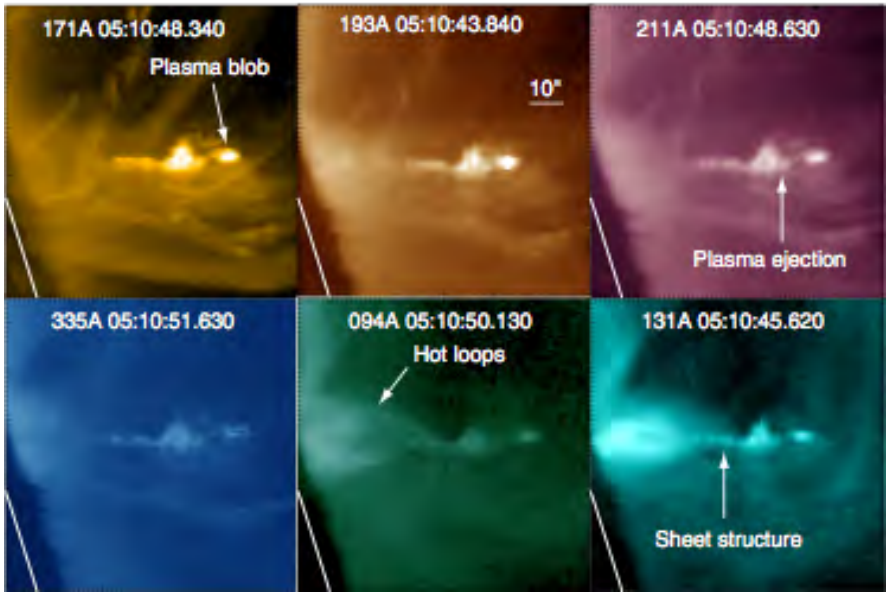


Fig 3

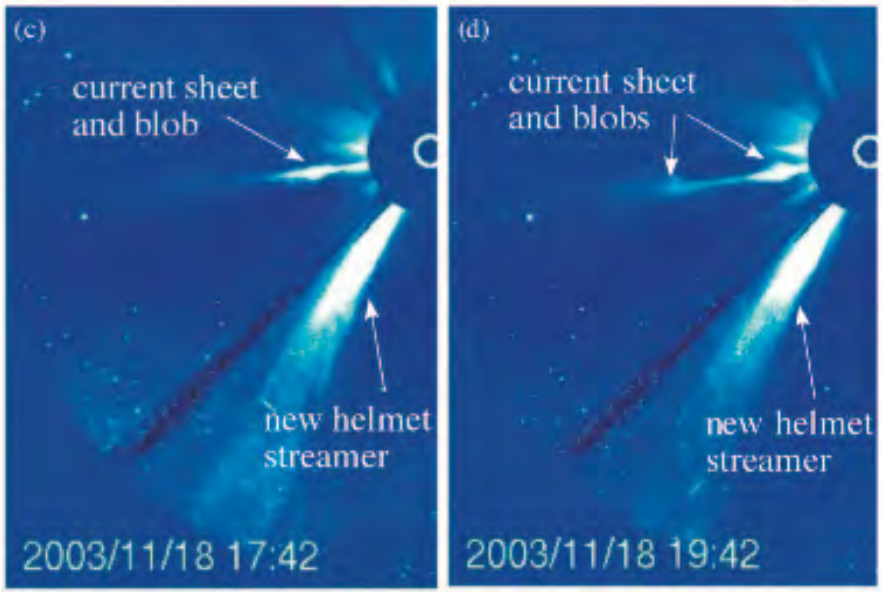


Fig 4

Fig 1: Savage et al. 2010 Fig 2: Ko et al. 2003 Fig 3: Takasao et al. 2012 Fig 4: Lin et al. 2004

Different from Plasmoid Observations

Fig 1

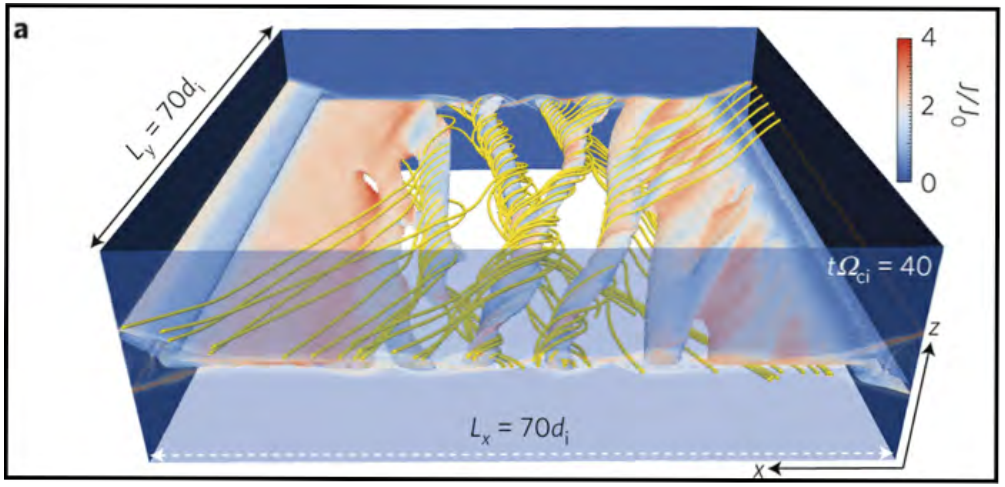
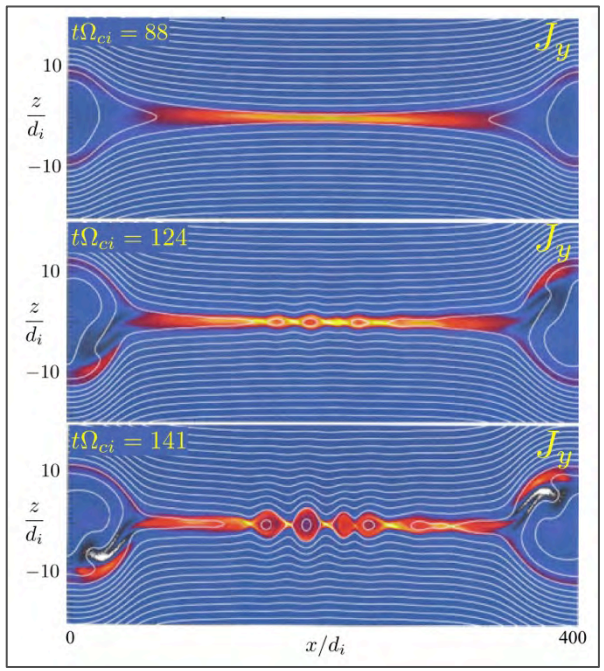


Fig 2



- Thin flux tubes created during the reconnection process across the current sheet.
- Plasmoids a 3-D product of reconnection concurrent to single loop creation.

Fig 3

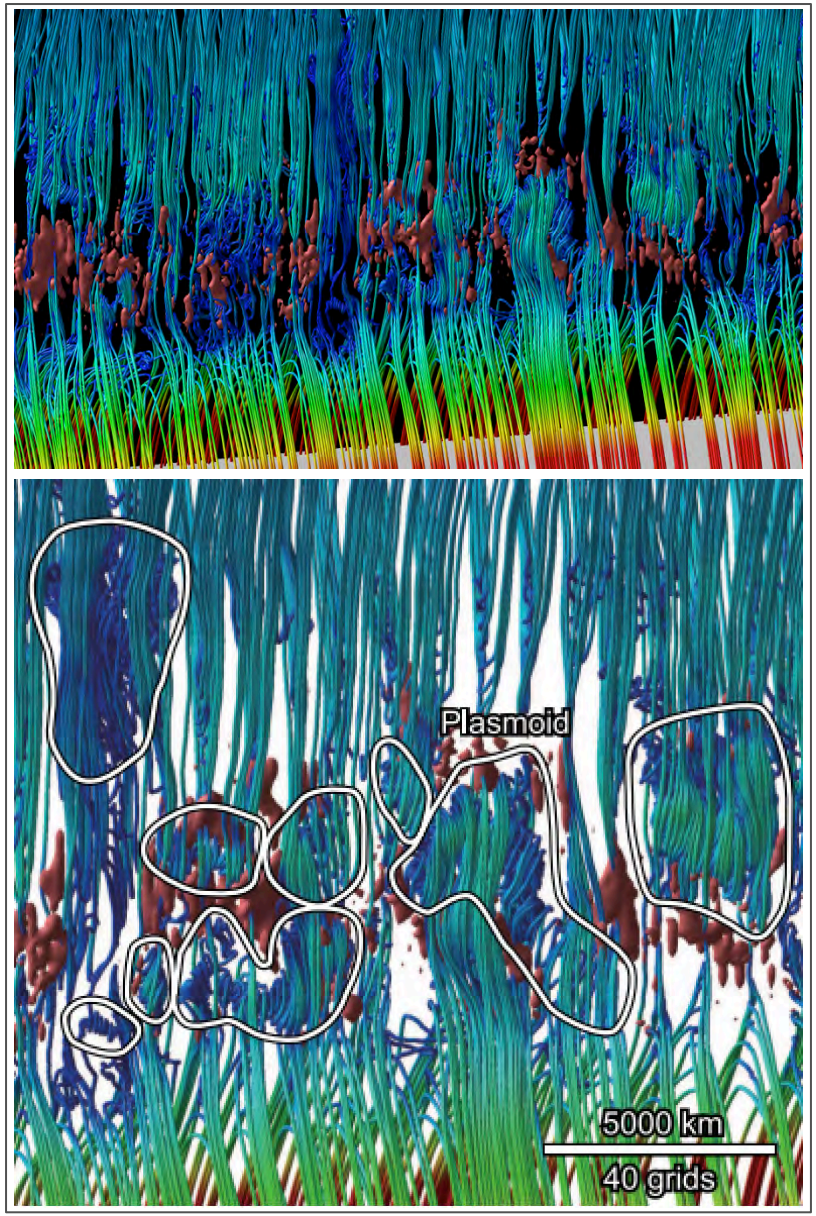
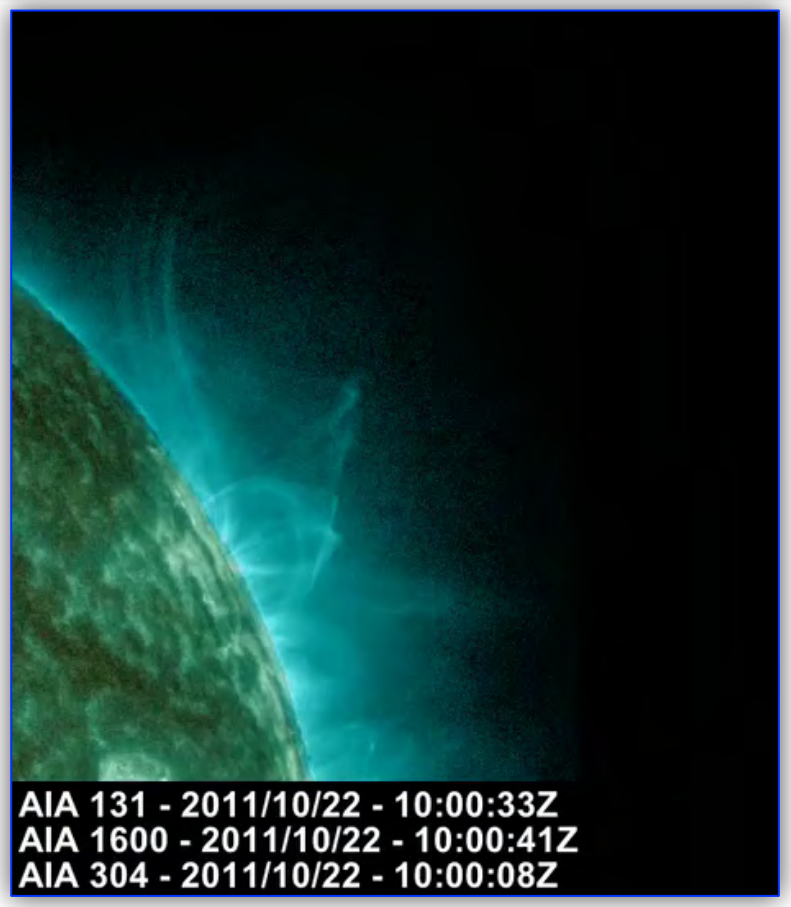
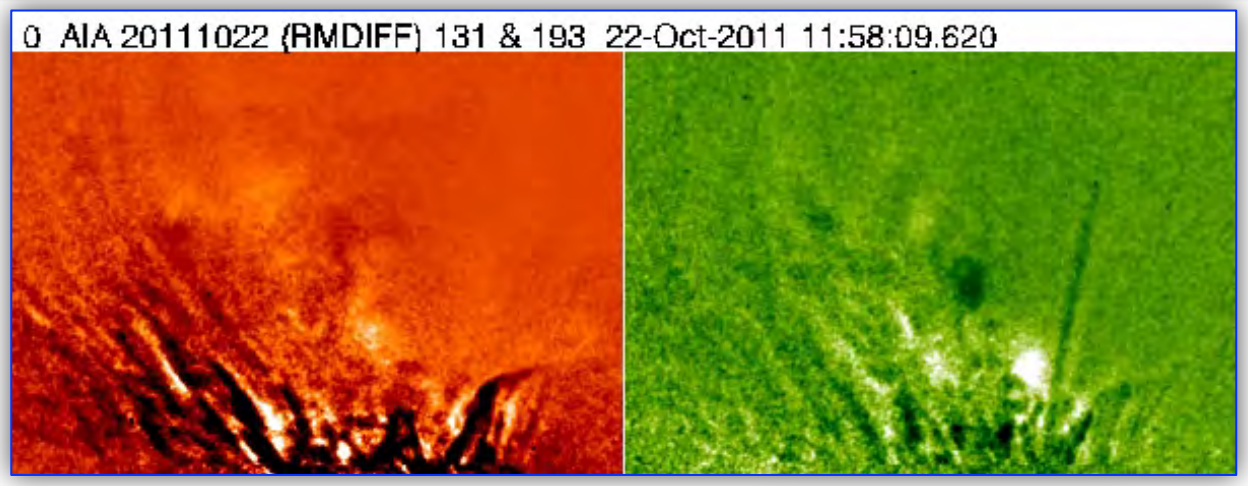


Fig 1, 2: Daughton et al. 2012

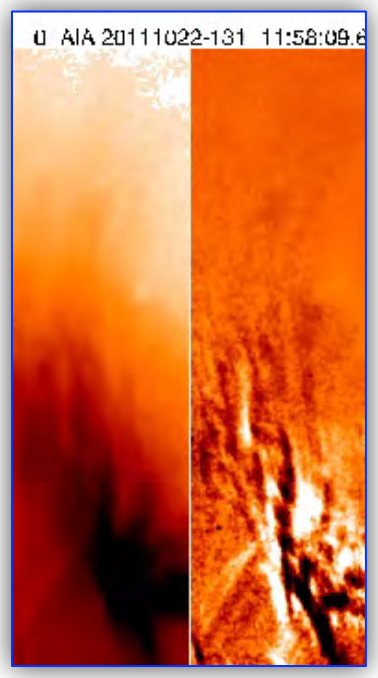
Fig 3: Nishizuka et al. 2013

SADs + SADLs



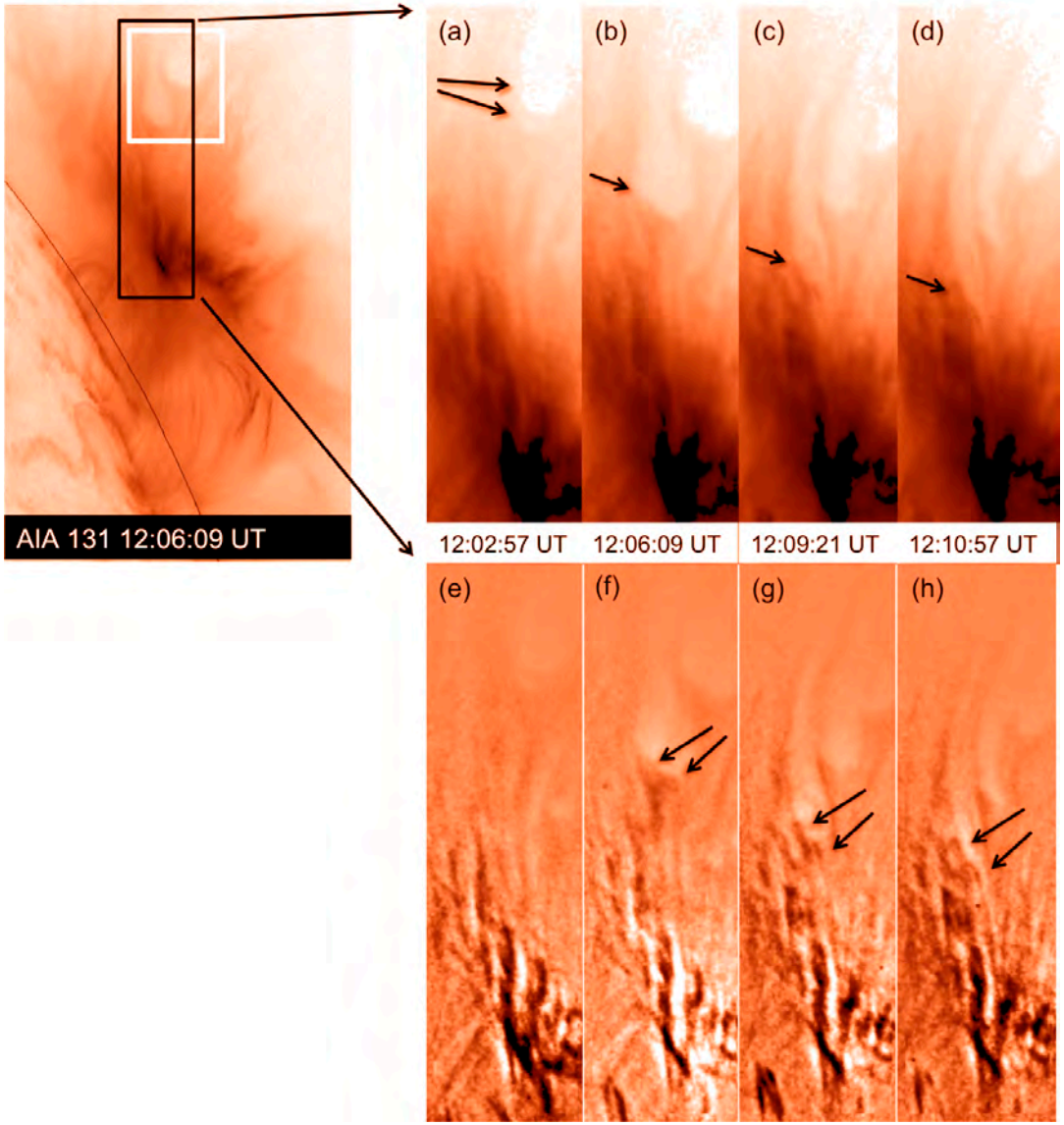


- Hot AIA channels. (2-10 MK)
- Differenced
- Reverse-scaled



SADs + SADLs

Fig 1

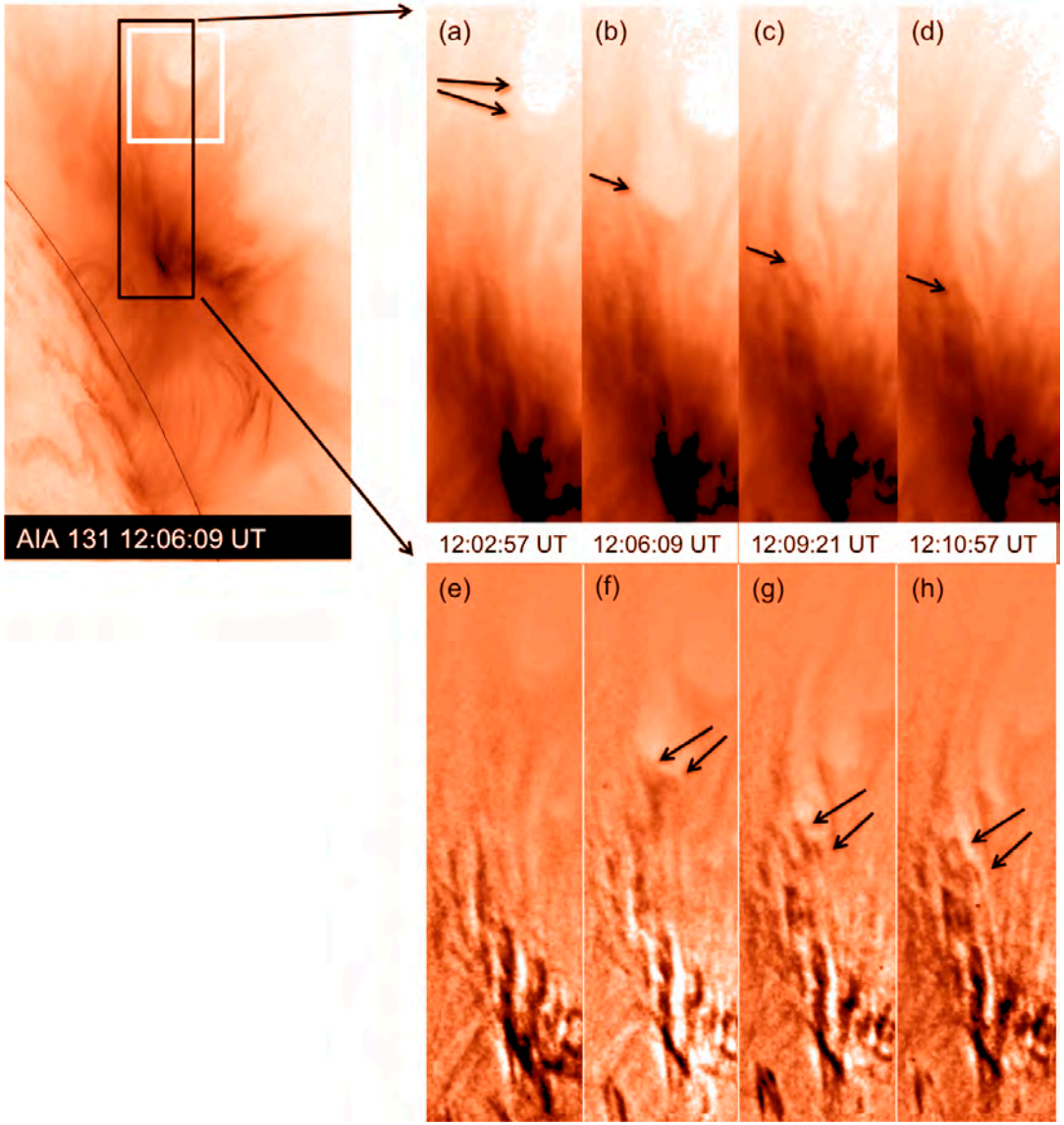


- SADs appear to be voids created by loops (SADLs) shrinking through the fan plasma.

Fig 1: Savage et al. 2012

SADs + SADLs

Fig 1



- SADs appear to be voids created by loops (SADLs) shrinking through the fan plasma.

Fig 2

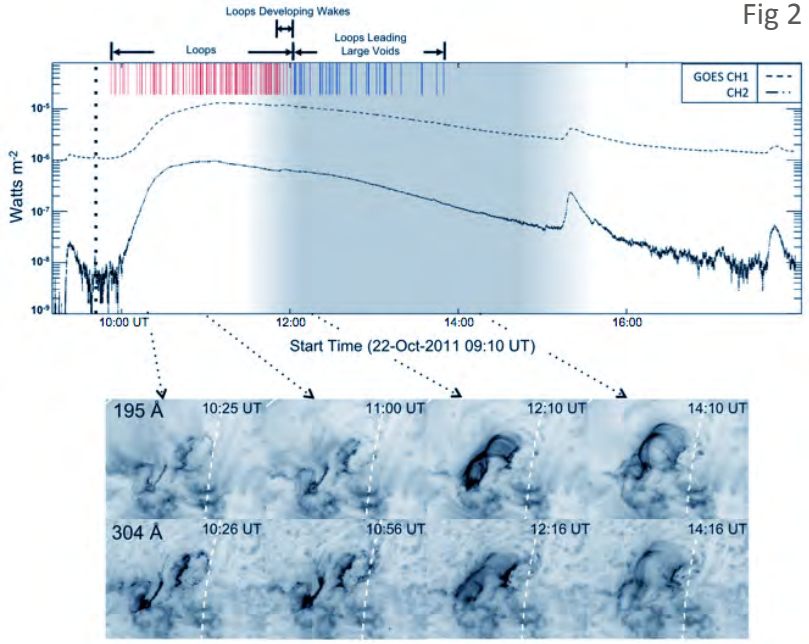


Fig 1, 2: Savage et al. 2012

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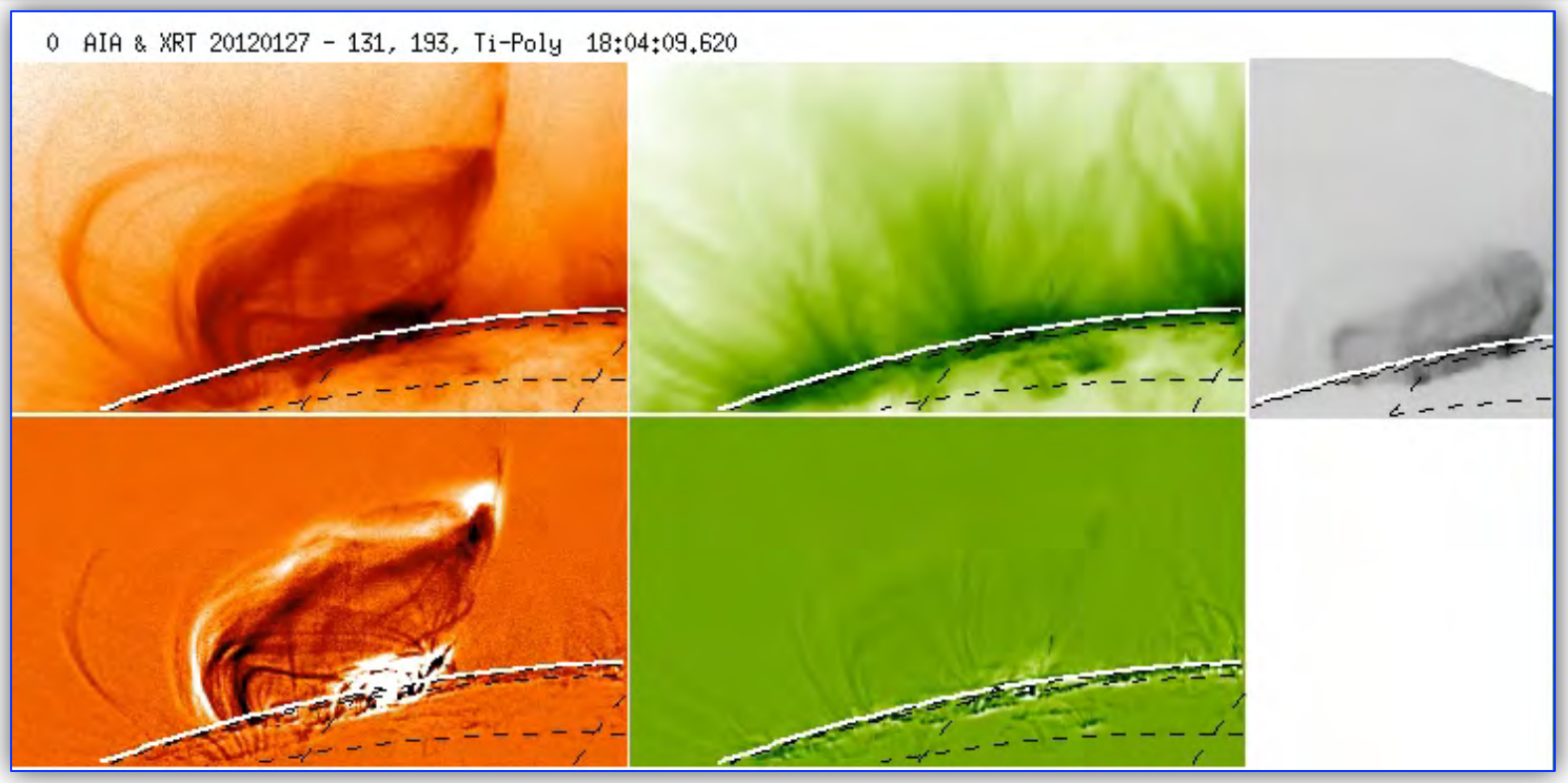
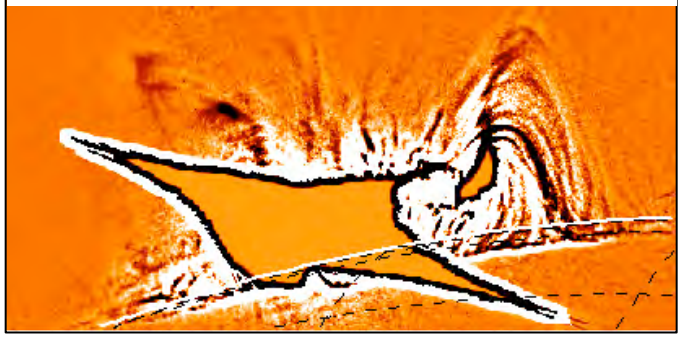


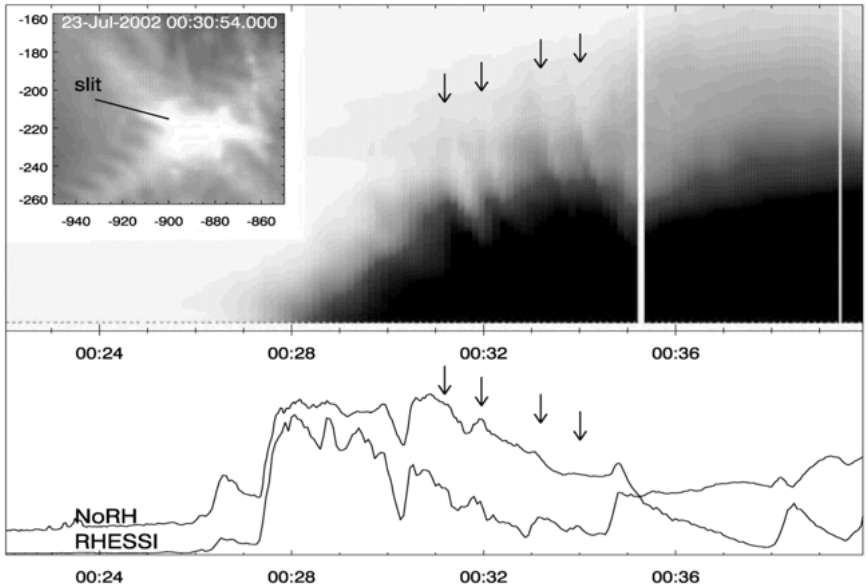
2012 Jan 27, SDO/AIA



Particle Acceleration & Heating

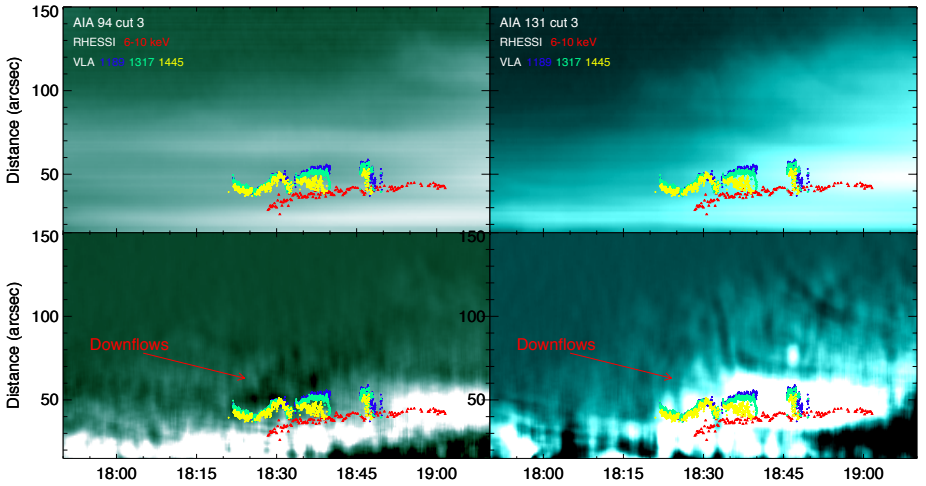
RHESSI + TRACE

Fig 1



VLA + AIA + RHESSI

Fig 3



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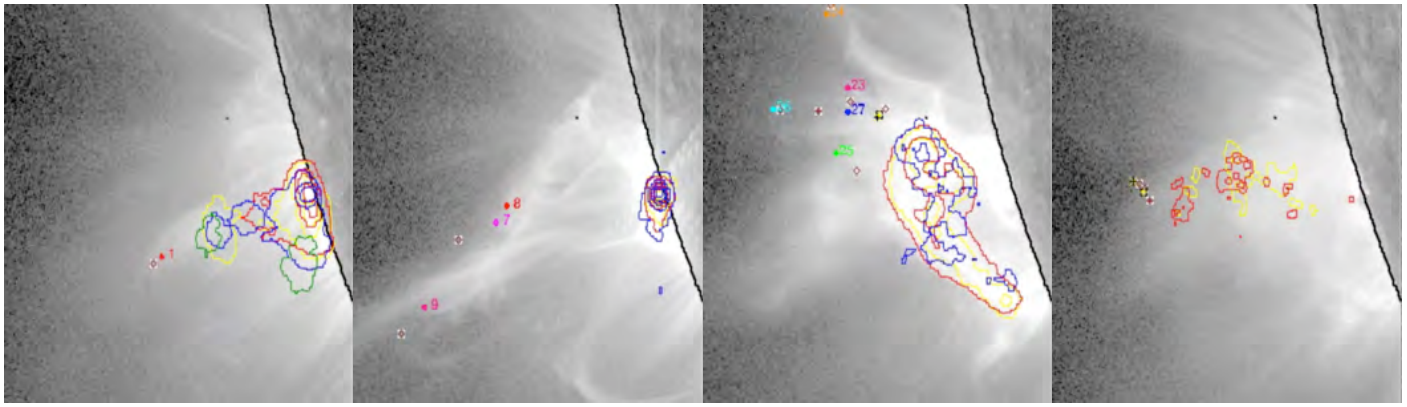


RHESSI + AIA

Savage – 2010 Nov 3 flare

Fig 1: Asai et al. 2004 (Khan; Liu)

Fig 3: Chen et al. 2014; 2015

Diagram Models

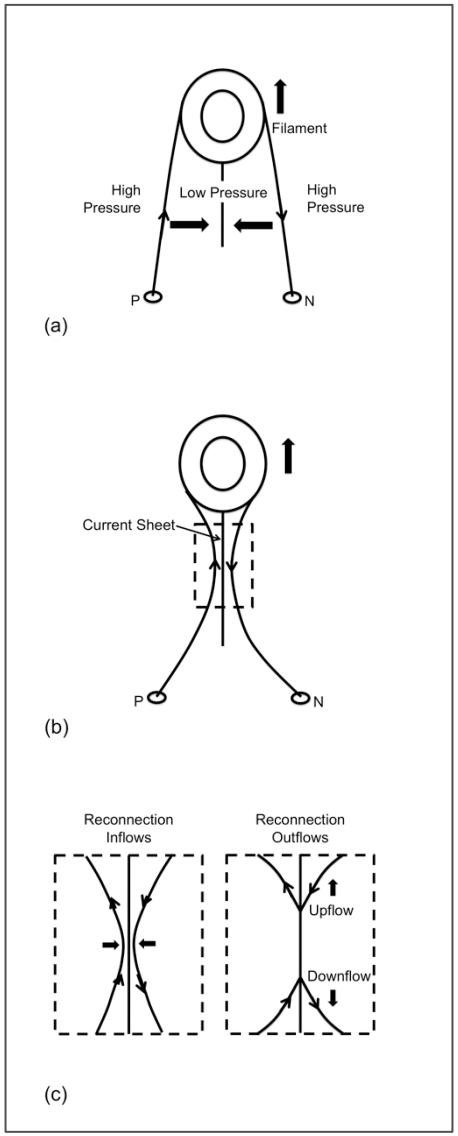
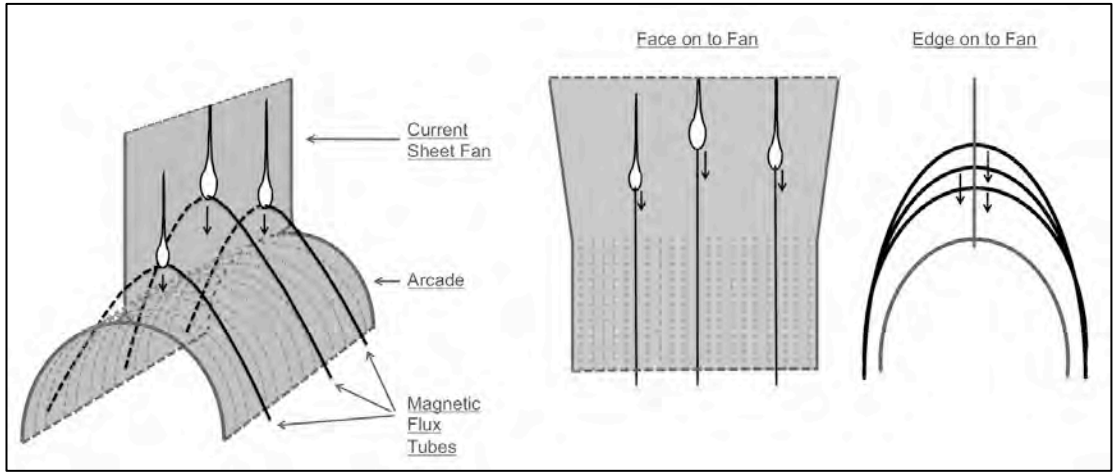
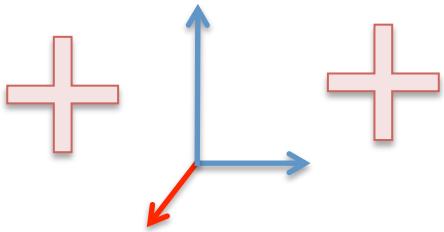


Fig 1

Fig 2





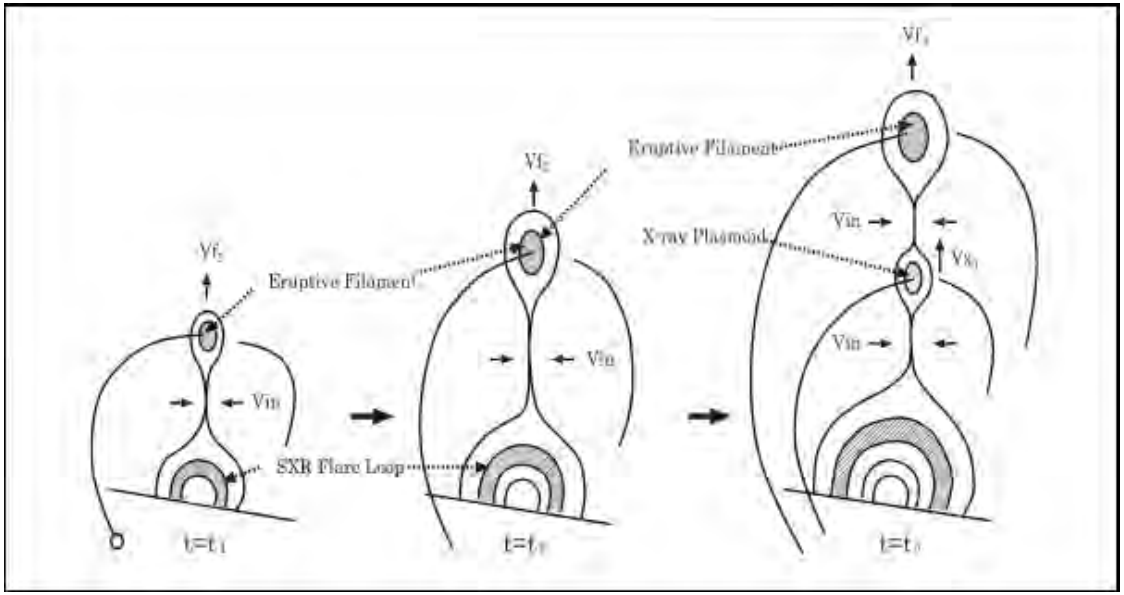


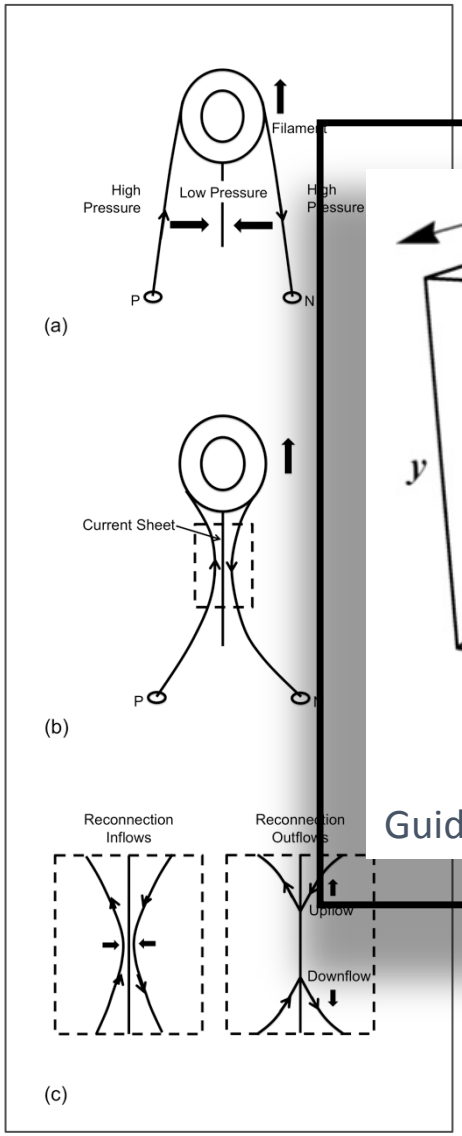
Fig 3

Fig 1, 2: Savage et al. 2012

Fig 3: Ohyama & Shibata 2008

3D is Pivotal

Fig 1



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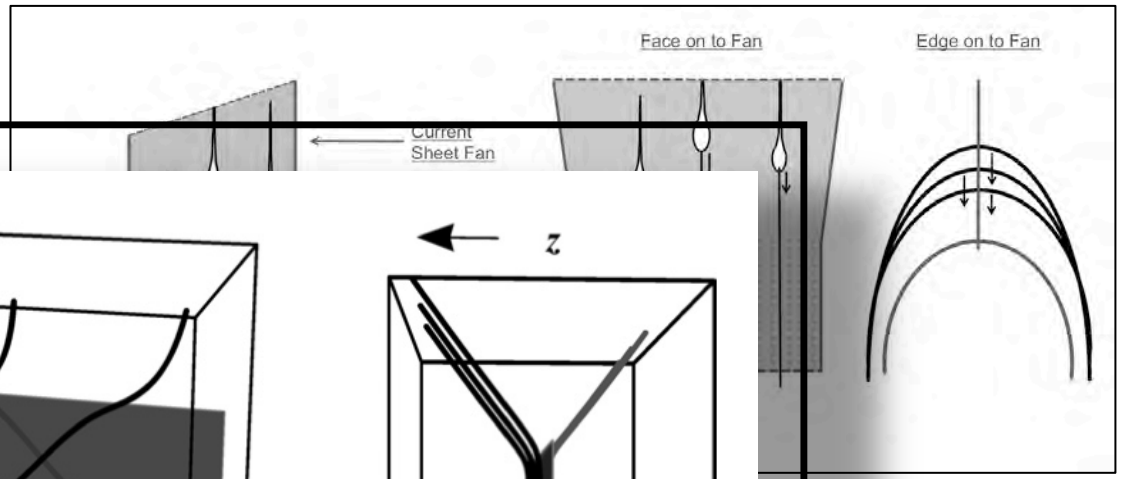
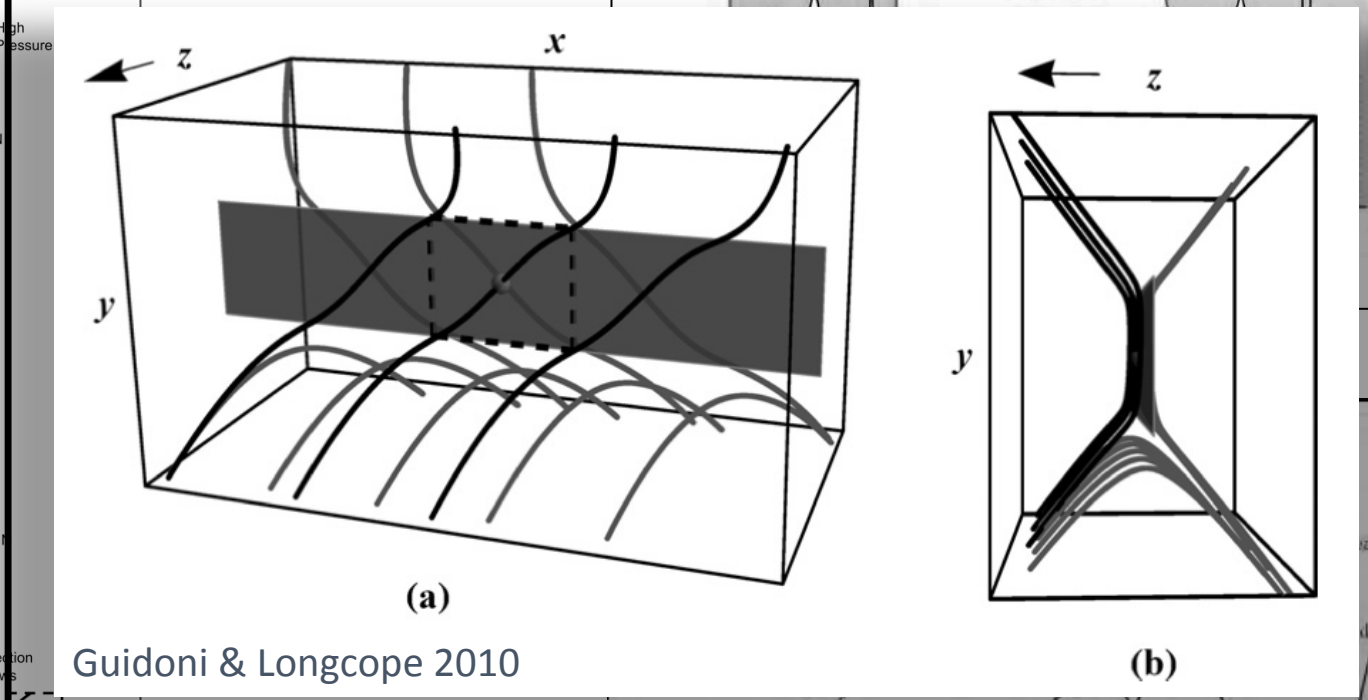
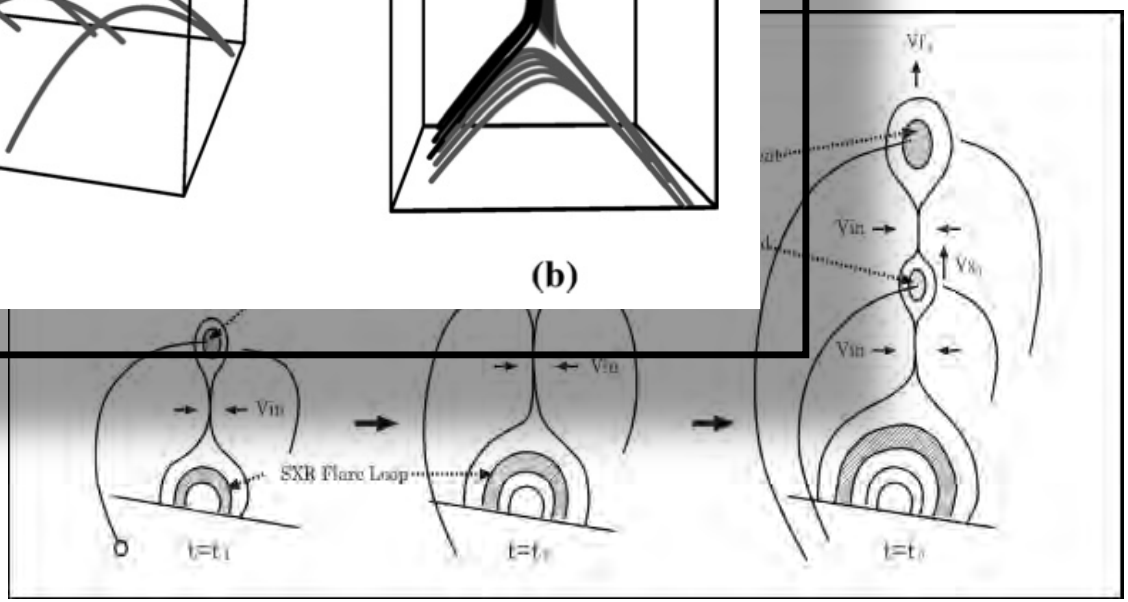




Guidoni & Longcope 2010

Fig 3



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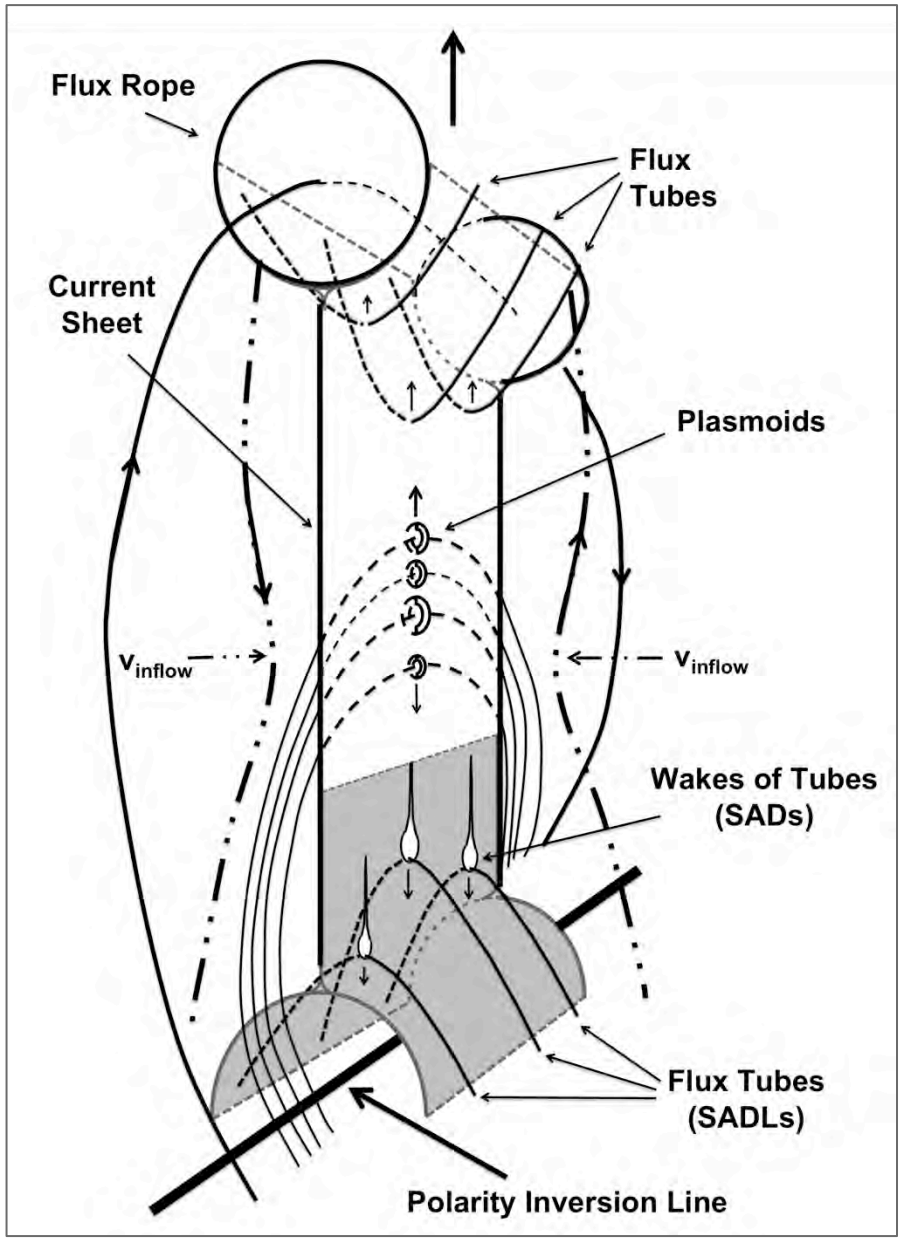


- Basic reconnection scenario, post initial flux rope formation and release.
- General organization of the magnetic field of the various components (SADs, SADLs, plasmoids).
- Field lines reconnect across the current sheet to form outflowing flux tubes while plasmoids form along the current sheet.
- SADs are formed as the flux tubes (SADLs) retract through hot plasma in the fan (*otherwise, only SADLs are observed*).

Fig 1: Savage et al. 2012

Strong potential analogy with magnetotail substorms

Fig 1

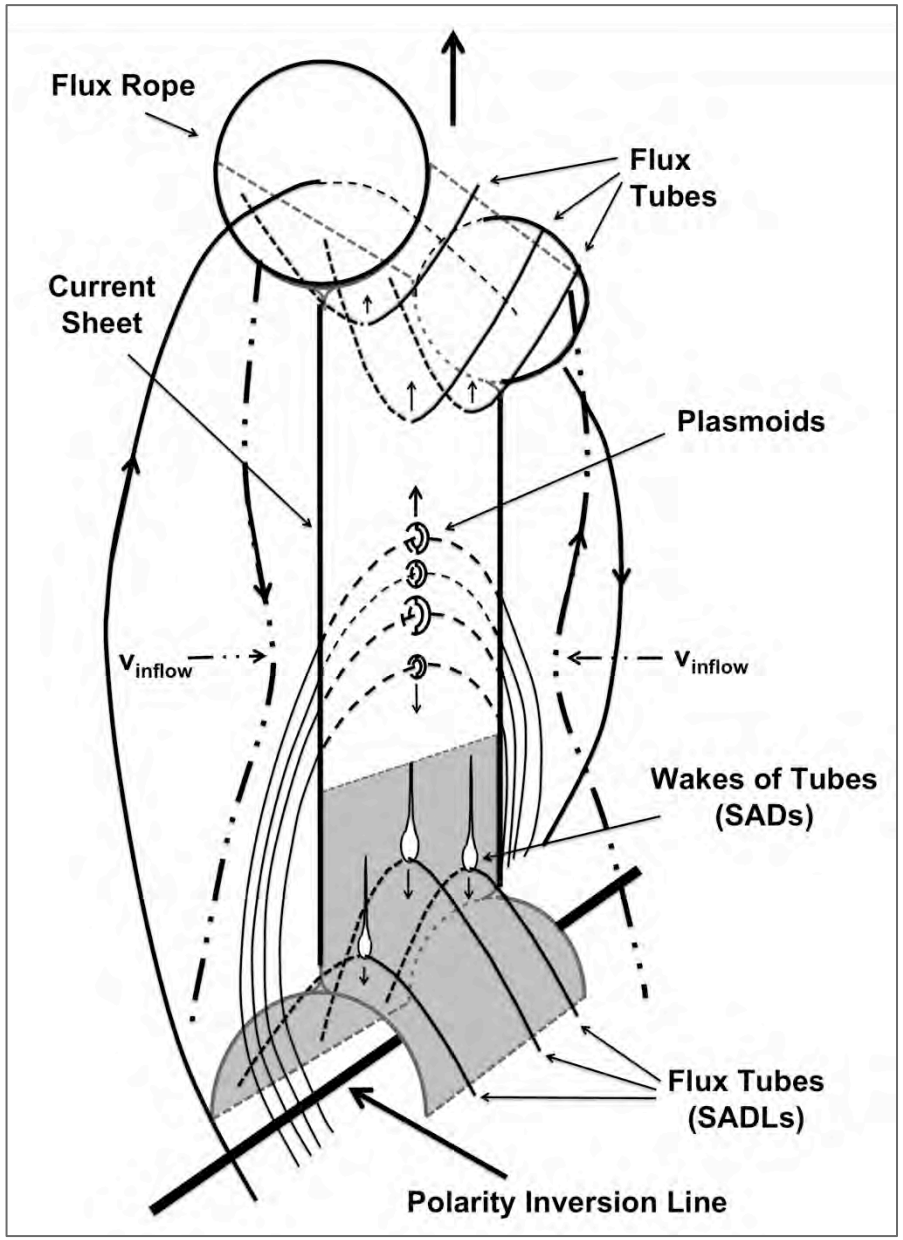


Fig 2

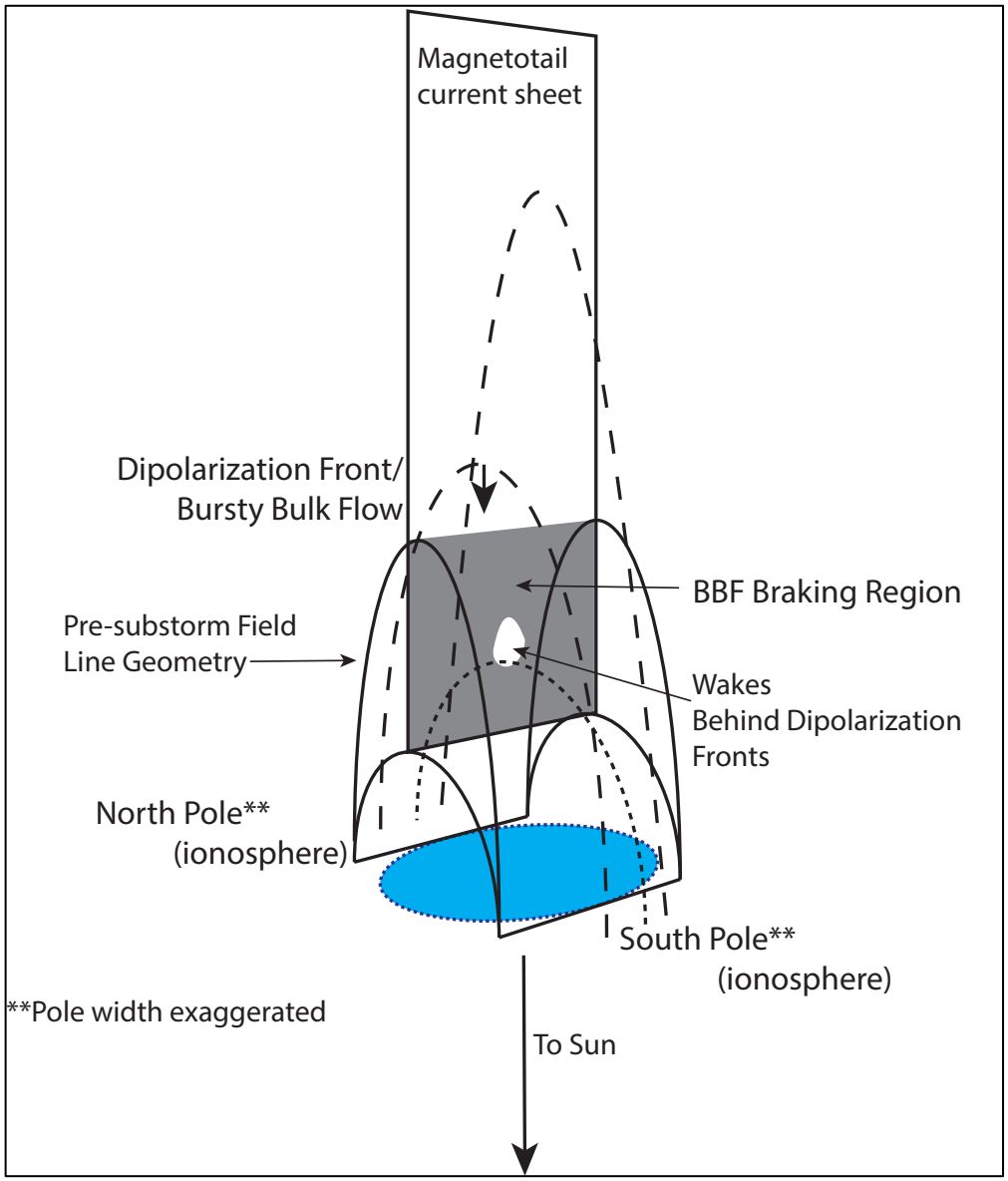


Fig 1: Savage et al. 2012

Fig 2: Courtesy of A. Kobelski, Reeves et al. 2008

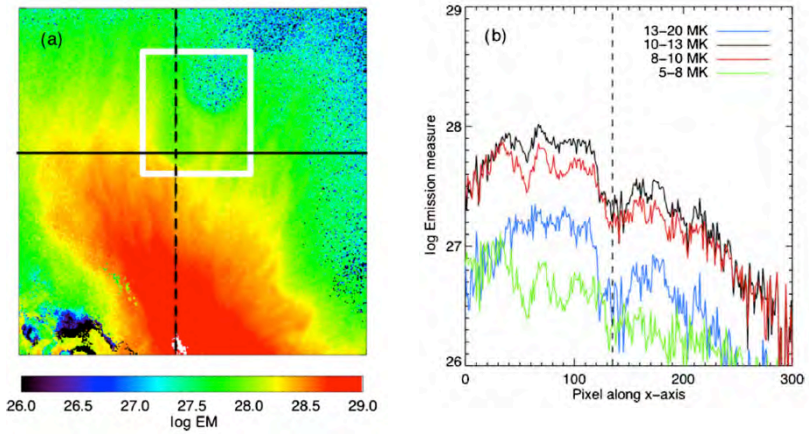
Using THEMIS for comparison to *in situ* data

Substantial density drop following the dipolarization event!

Courtesy of Adam Kobelski and David Malaspina

Model Constraints

OBSERVED TEMPERATURE AND DENSITY ALWAYS LOWER THAN FAN



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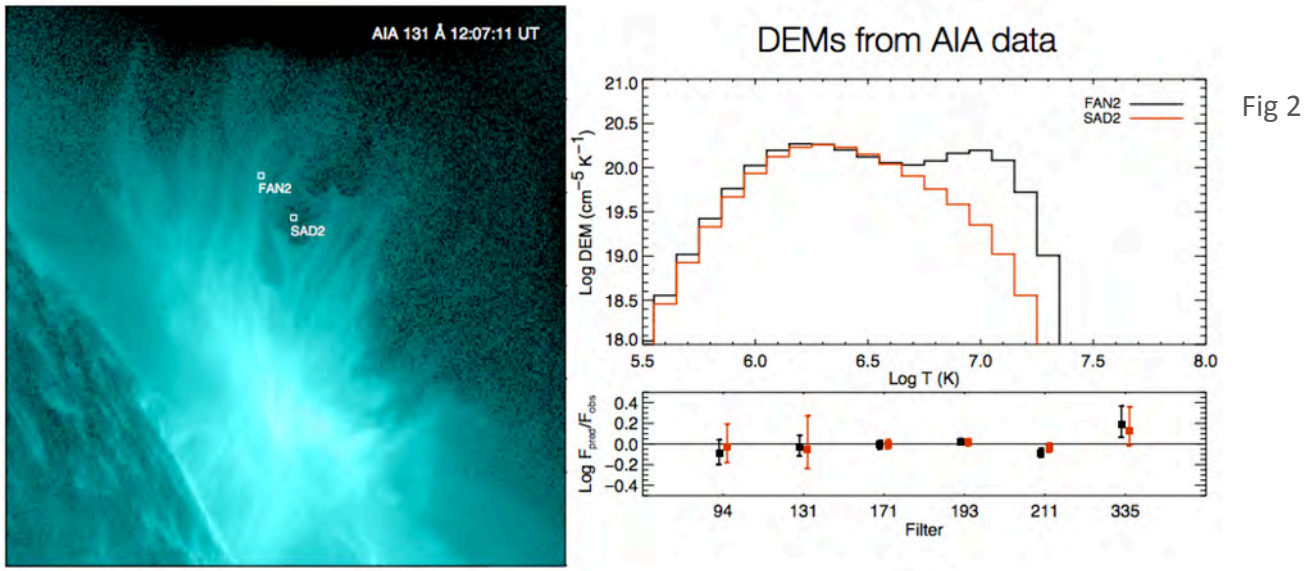
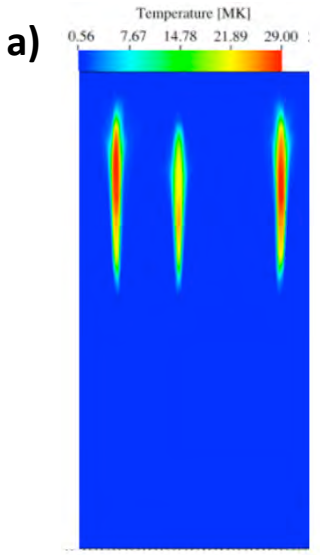


Fig 2

Fig 1: Savage, McKenzie, & Reeves 2012

Fig 2: Hanneman & Reeves 2014

Model Simulations

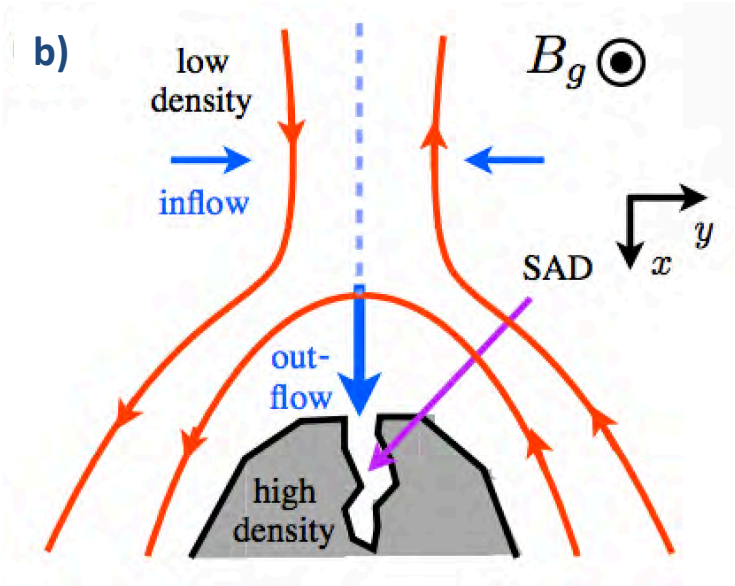


Pressure pulse + MHD wave

(T >> fan)

Too hot with respect to the surroundings

Fig 1: Cecere et al 2012

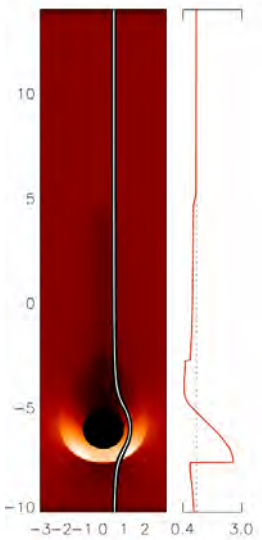


Reconnection outflows

(T ~< fan)

Incorrect geometry with respect to observations

Fig 2: Cassak et al 2013



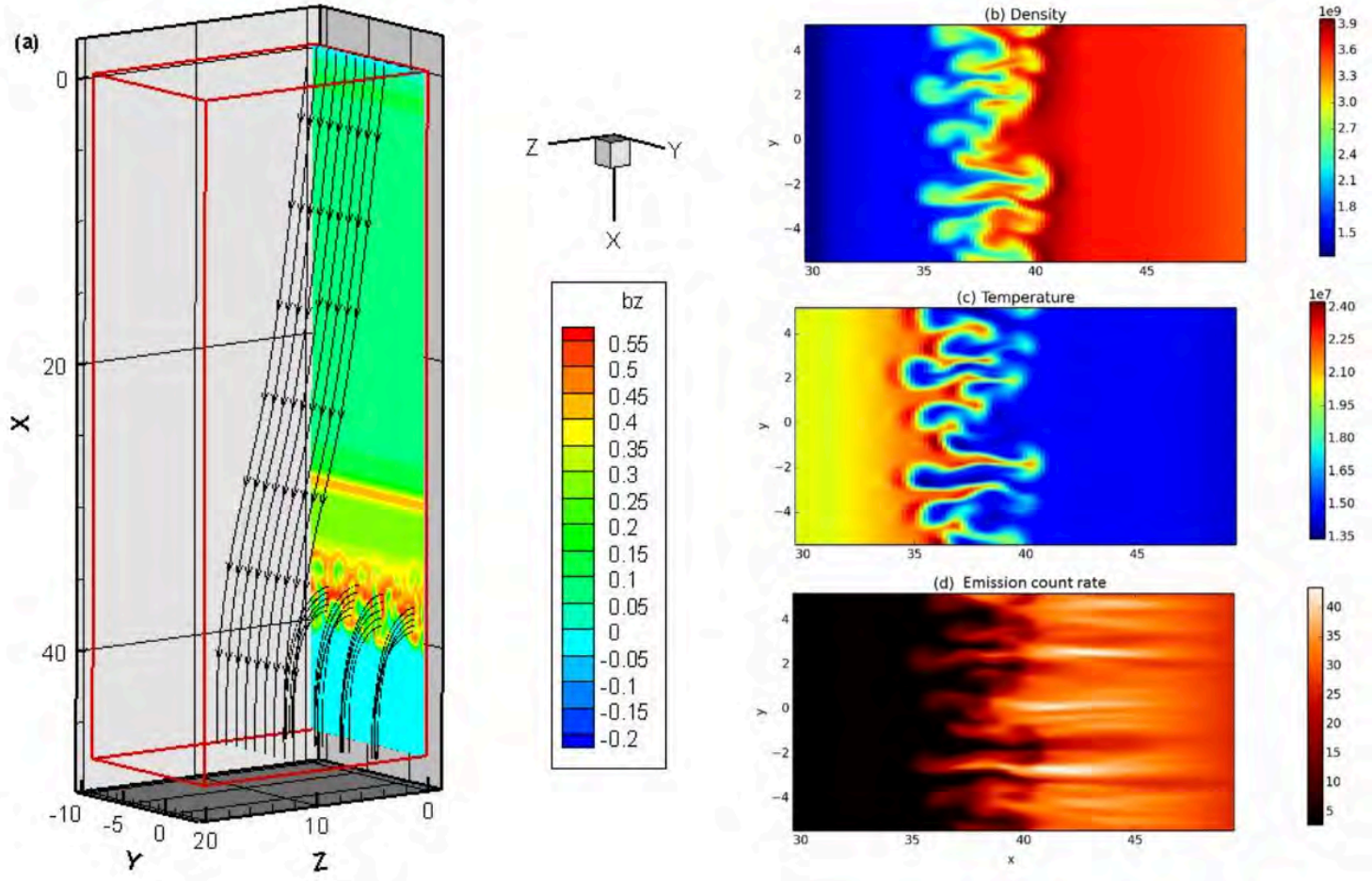
Peristaltic pumping

(T ~< fan)

Incomplete, feasible; Difficult to match to observations

Fig 3: Scott et al 2013

Model Simulations



Rayleigh-Taylor Instabilities behind retracting flux tubes (T > fan)

Too hot with respect to the surroundings BUT Best match to observations to date (3D!) although early in development

Fig 1: Guo et al 2014

SADs in the Extended Corona

Fig 1

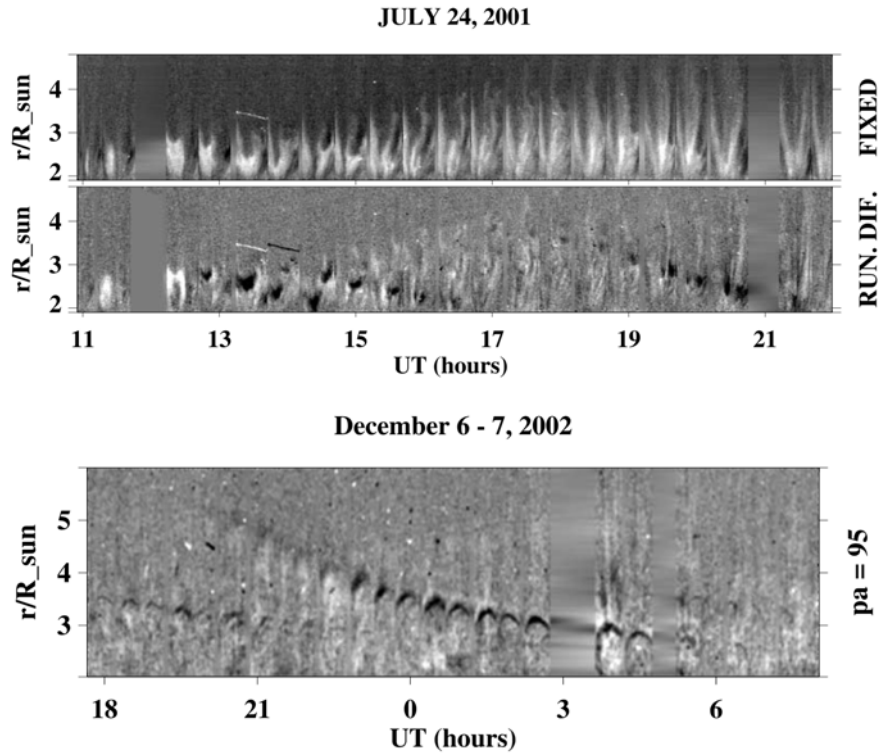
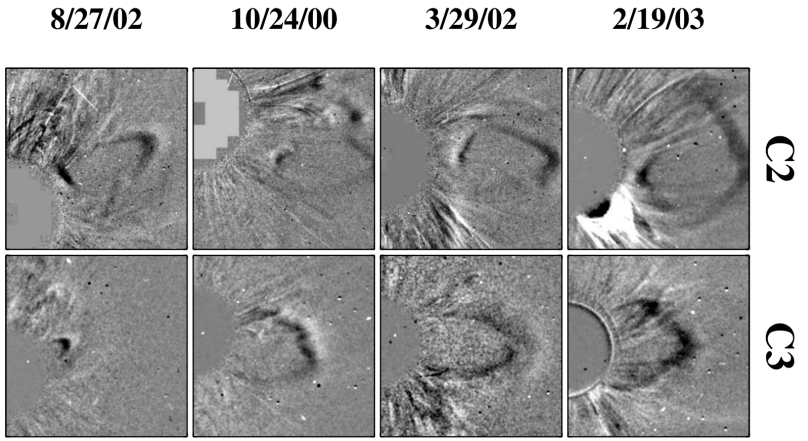
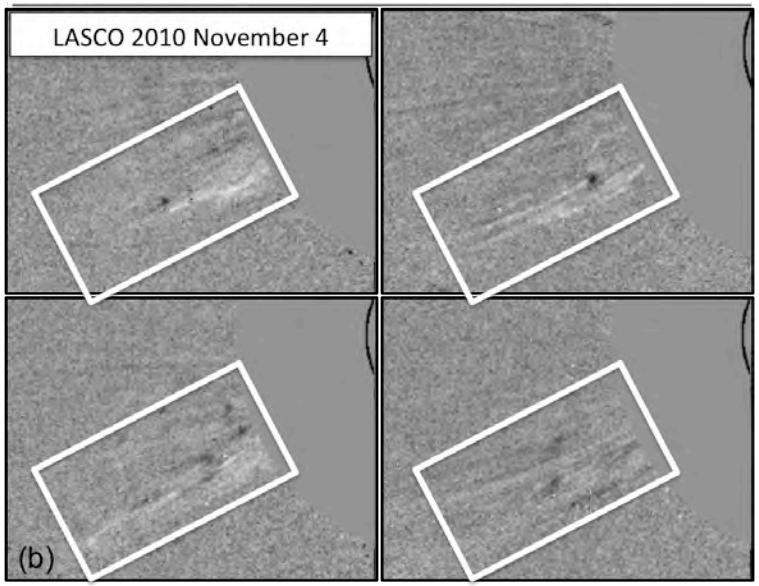


Fig 2





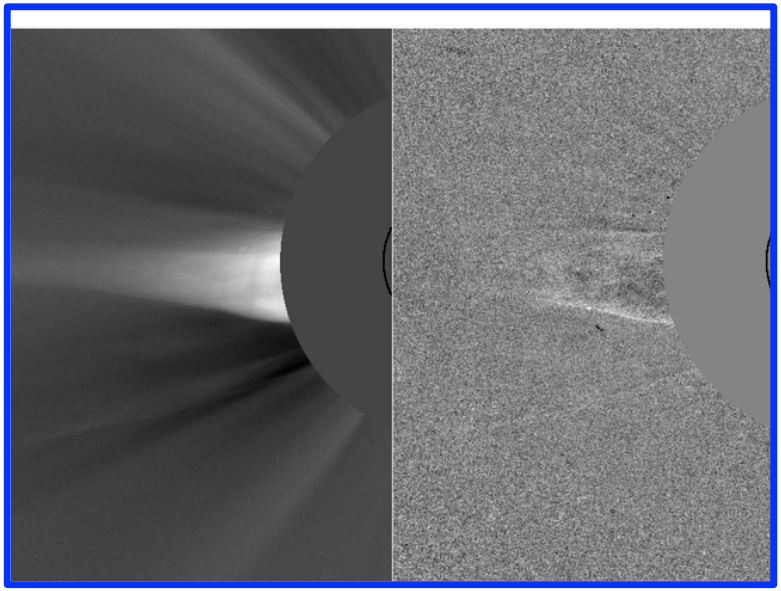


Fig 1: Sheeley, Warren, & Wang 2007

Fig 2: Sheeley & Wang 2007

Go see Matthew West's talk Friday @ 11:45

SADs in the Extended Corona…

SADs in the lower corona are typically observed well after reconnection has occurred.

In the extended corona, we are better able to observe the migrating reconnection sites.

Coronagraphs allow us to see reconnection develop behind the CME while looking directly at the density.

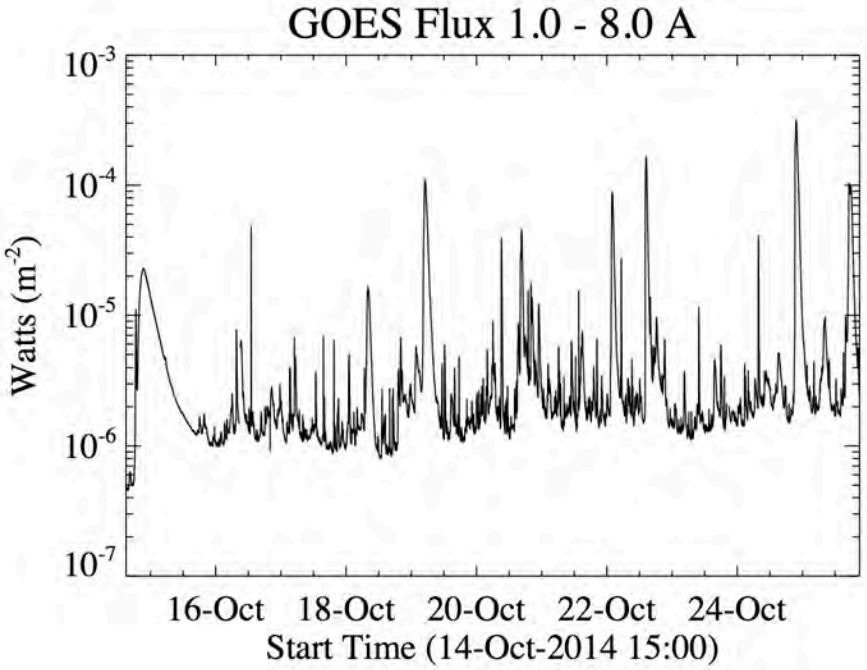


Fig 1

"Giant Arches" Flare – 2014 Oct 14

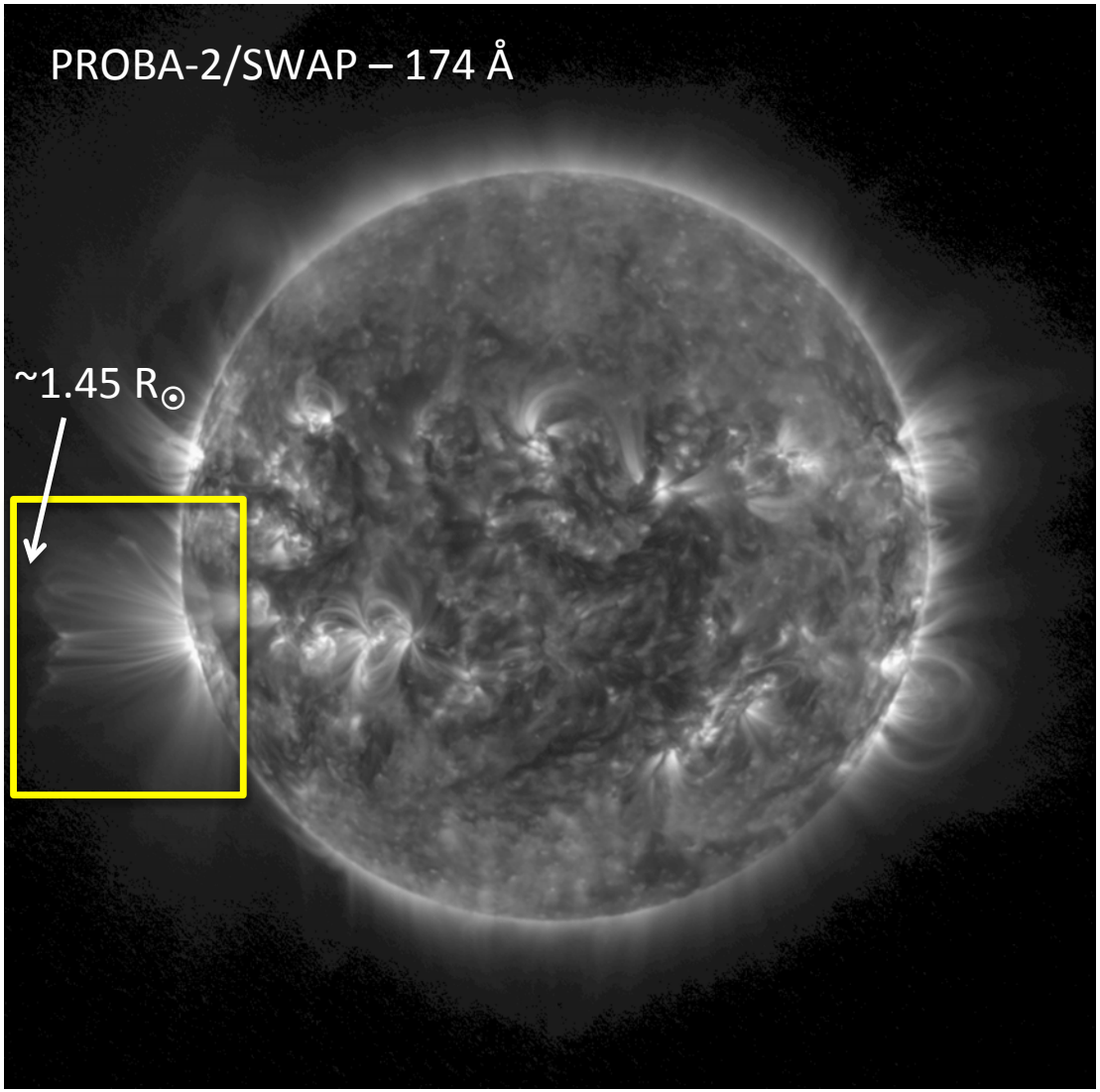


Fig 1: West & Seaton 2015

SADs in the Extended Corona…

LASCO C2
PROBA-2/SWAP
AIA 131 Å

A: Flattened from a year's worth of data

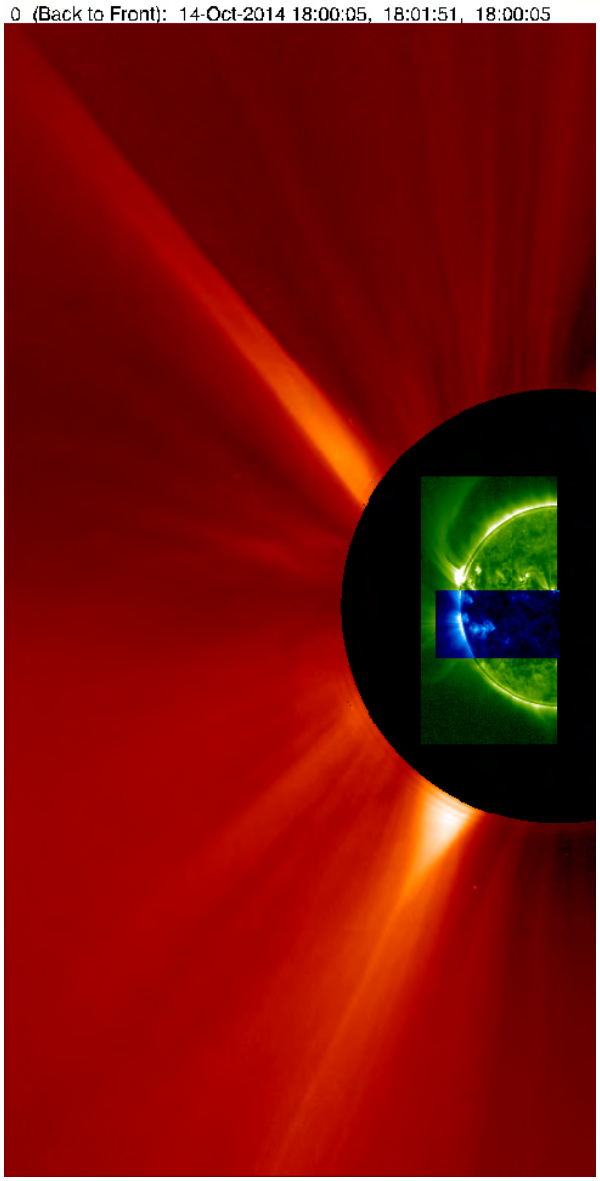
Cleaned (cosmic rays, background stars, planets)

Attenuated disk

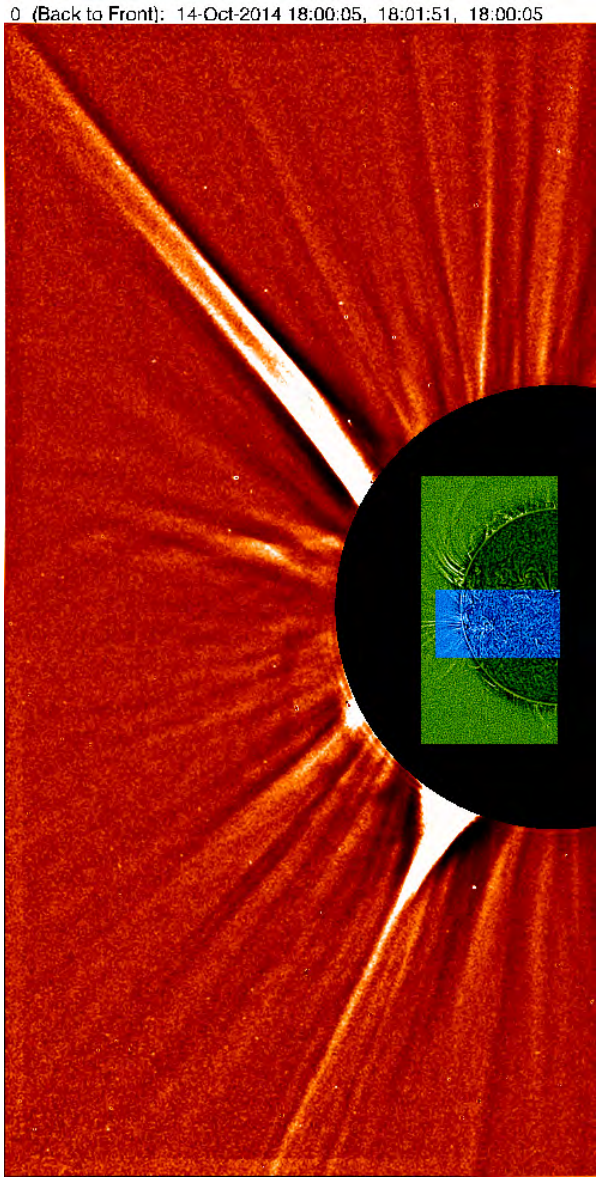
B: Smooth-Differenced

- Scaled

A



B



SADs in the Extended Corona…

LASCO C2
PROBA-2/SWAP
AIA 131 Å

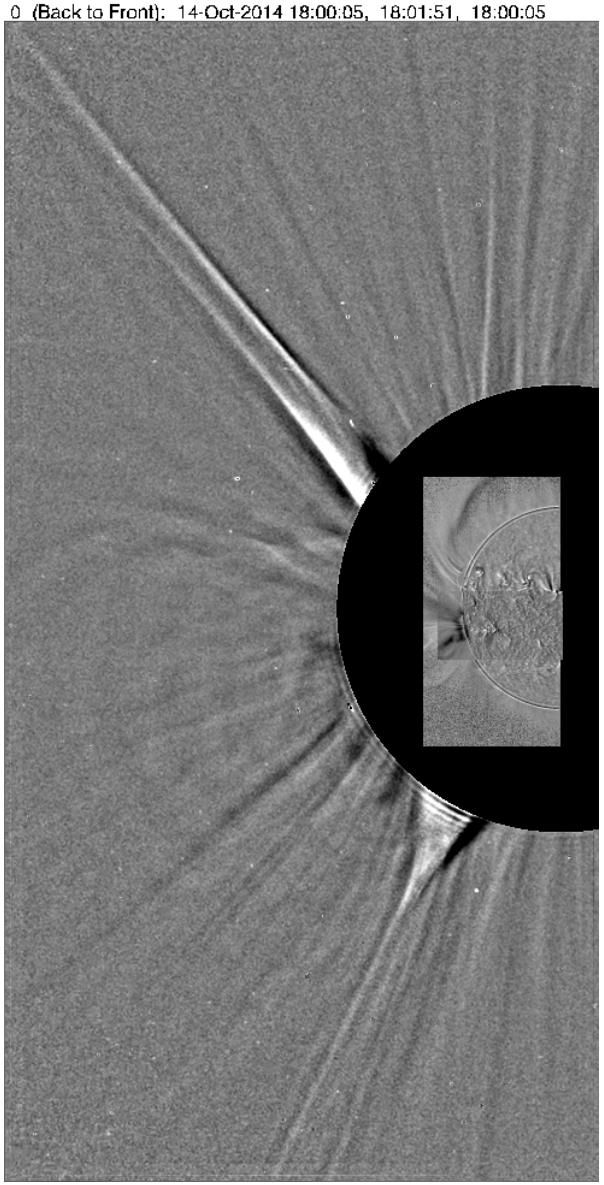
C: Run-Mean-Differenced

D: Smooth-Differenced

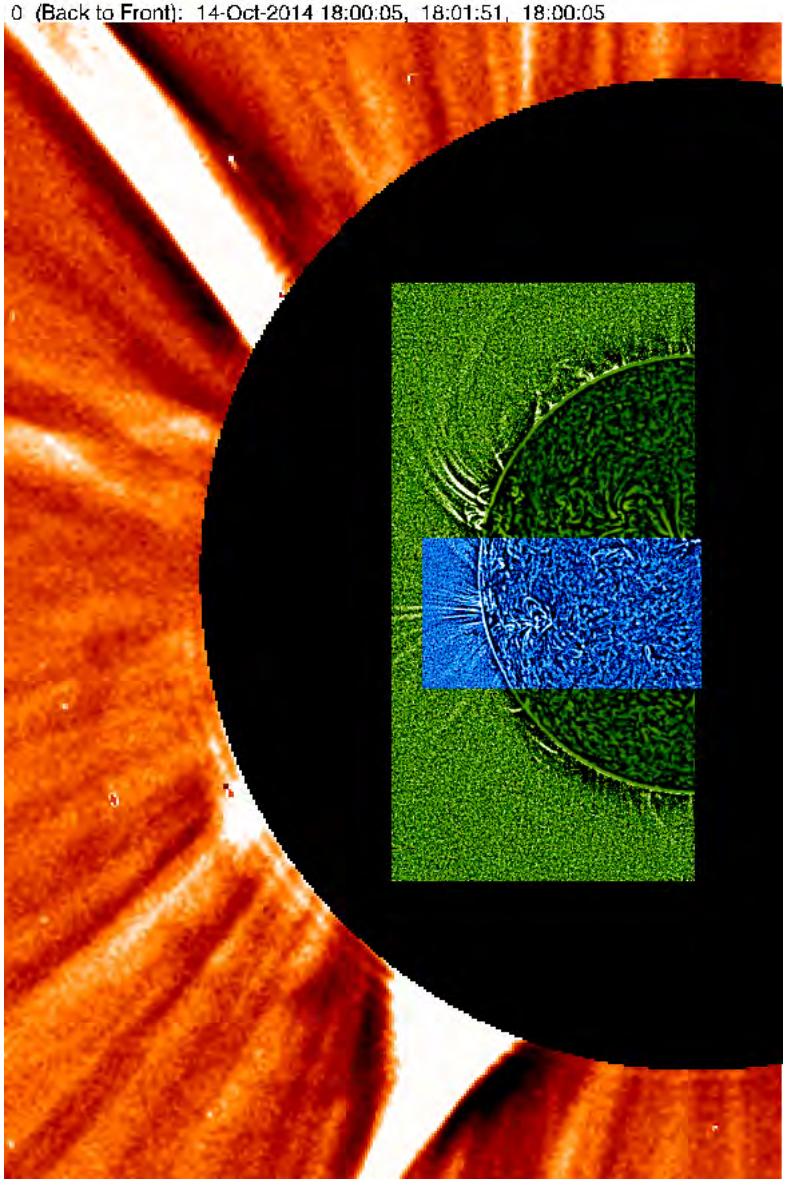
Extracted

- Scaled

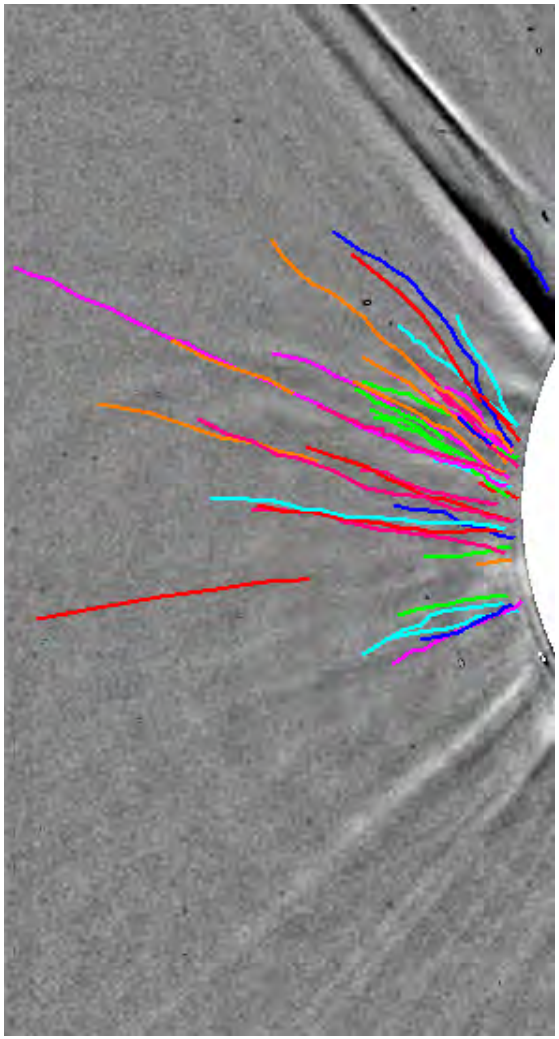
C

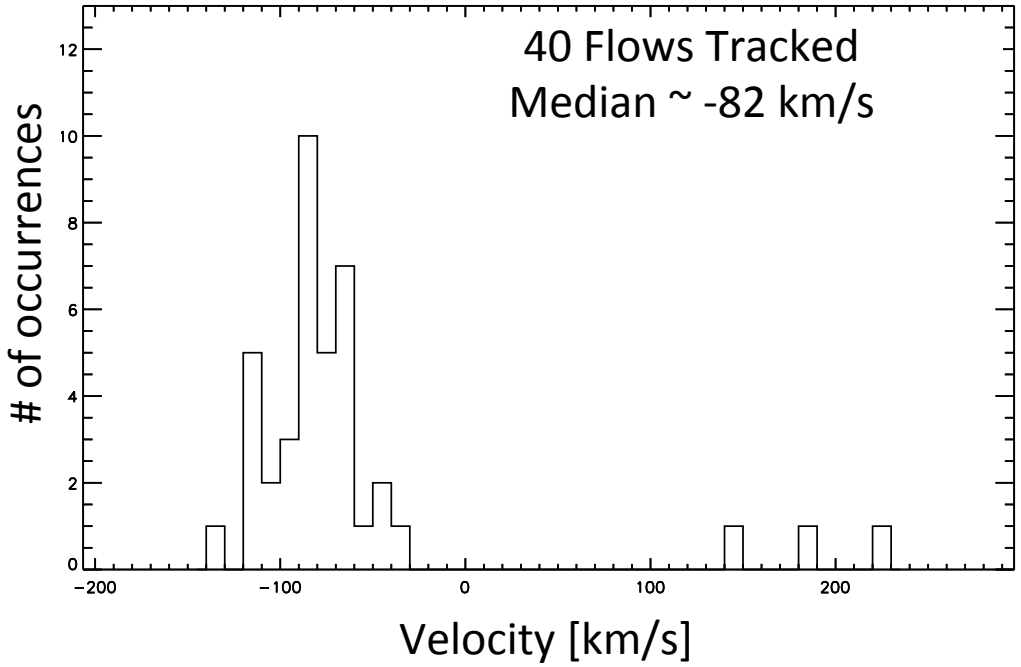


D



SADs in the Extended Corona…





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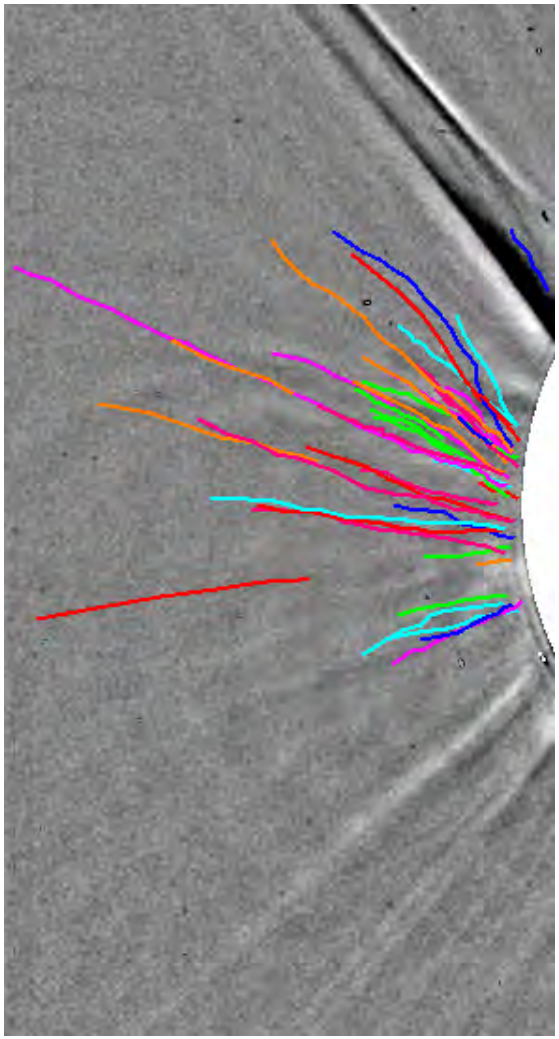
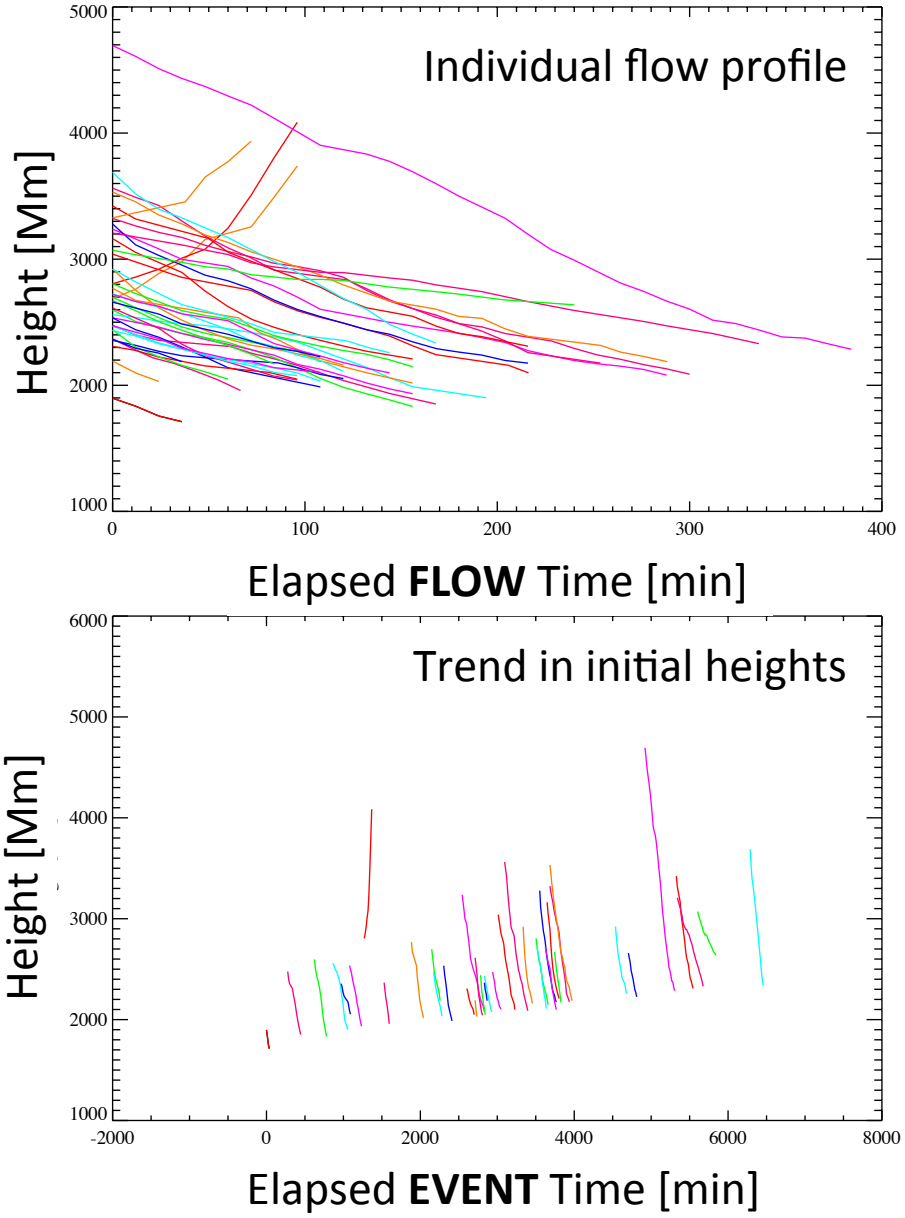
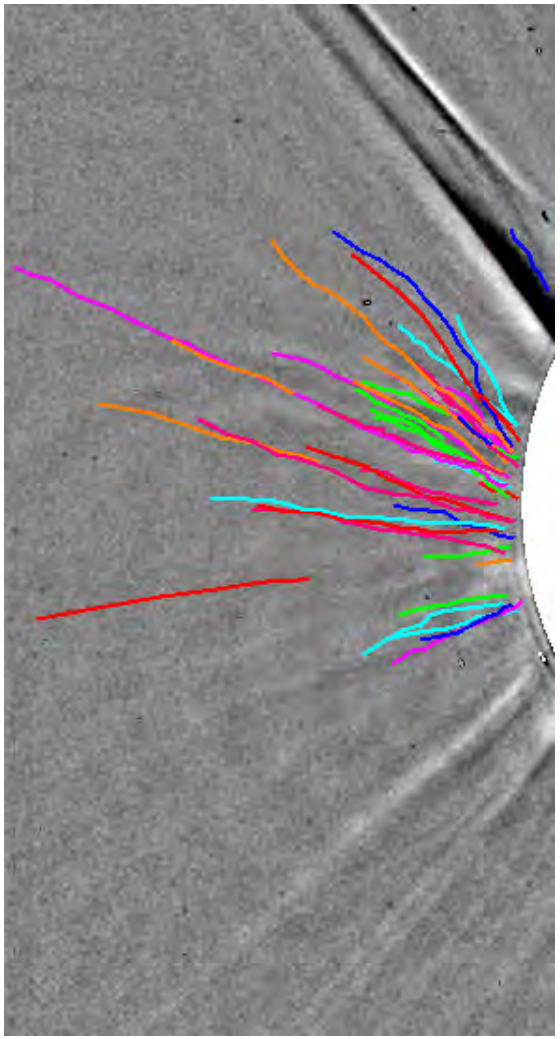




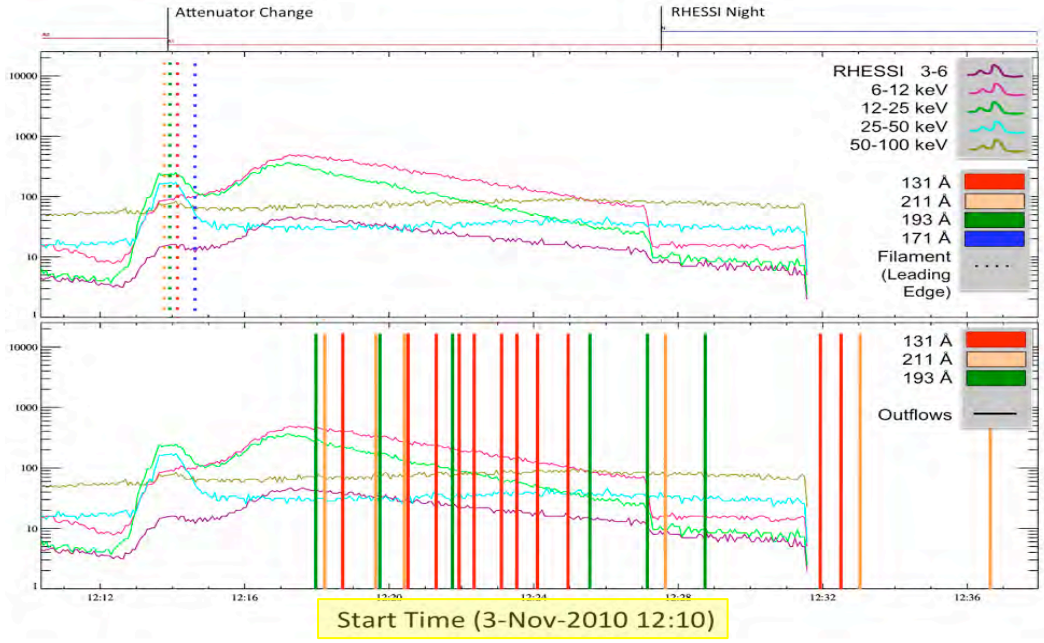
SADs in the Extended Corona…

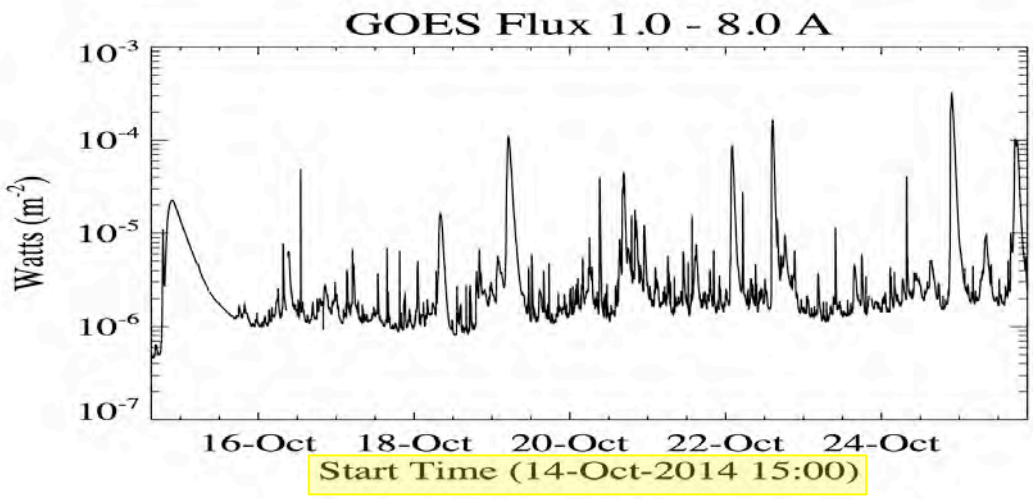


TBD

1. **Correlate flows directly to lightcurve as done for 2010 Nov 3rd event**

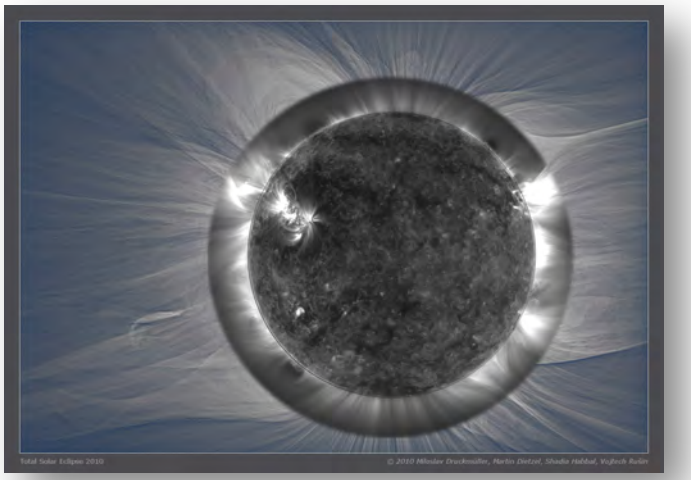
2. **Spatially and temporally correlate RHESSI and Hinode/XRT X-ray contours with outflows.**





Summary & Forward Work

- Continuation of shrinking loops imparts energy into the current sheet long after the flare. Clearly.
  - But for an entire week??
  - Does this happen all of the time?
  - How did this one grow so large?
    - Density stratification? Active region interactions?
- Reconnection is fast and patchy.
- Add Hinode/XRT and RHESSI data (started).
- Do features track between fields of view both ways?
  - Initial work begun. (Some even in LASCO C3.)
- Need for instrumentation to fill the gap in observing the transition corona
  - Important to be in single wavelength
  - Possibly coming to an International Space Station near you….



An EUV Wide-Field Imager and Spectrometer for the ISS

Leon Golub[1] and Sabrina Savage[2] for the Coronal Spectrographic Imager in the EUV (COSIE) Team

(1) Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, (2) Marshall Space Flight Center (MSFC), Huntsville, AL

Abstract

The Coronal Spectrographic Imager in the EUV, COSIE, combines a wide-field solar coronal EUV imager (EUVC) and an on-disk EUV imaging spectrometer (EUVS). Located on the International Space Station (ISS), the goal of the mission is to enhance our understanding of the dynamics of the Transition Corona (the region in which the coronal magnetic field transitions from closed to open), and to provide improved detection and tracking of solar eruptive events for space weather research.

Mission Goals and Objectives

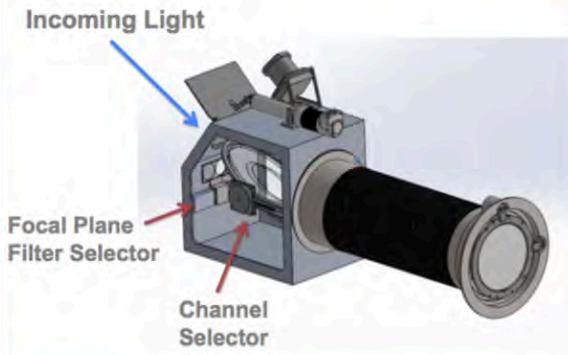
1. Understand the physical processes that alter the magnetic connectivity of the corona from closed to open and open to closed.	A. Observe steady coronal structures and their source region from the solar disk to the upper corona.
	B. Observe the temporal changes of the magnetic connectivity due to solar activity.
	C. Understand the hot coronal plasma associated with the magnetic structures both on and off disk.
2. Understand the global thermal structure of the corona.	A. Observe the evolution of active regions and associated changes in the slow solar wind.
	B. Characterize the temperature profile of the hot plasma associated with the slow solar wind.
	C. Measure the temperature and density changes associated with EUV waves, streamers and coronal cavities.
3. Trace the early evolution of coronal mass ejections and prominences as they propagate into the interplanetary medium and create space weather.	A. Observe the locations, velocities and acceleration profiles of coronal mass ejections from their on-disk source regions to >2.5$R_\odot$.
	B. Characterize the background plasma environment before the CME eruption.
	C. Identify the CME shock structure and identify regions of possible particle acceleration into interplanetary space.

Technical Overview

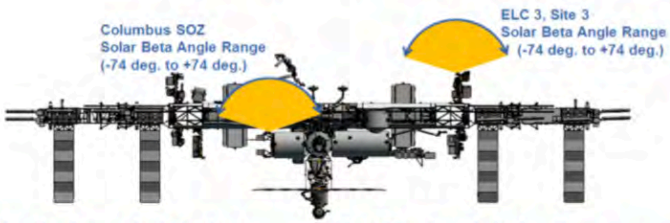
Design: SAO has produced a low-risk design for an EUV instrument with an MSFC pointing platform design

- **Non-occulting Coronagraph + Full-disk Slitless Spectrometer**
- Wavelength: 185-205 Å
- Field of view: Full disk out to 3+ $R_\odot$
- Cadence: 10 s to 1 minute
- Plate Scale: ~ 3 arcsec/pixel
- Pointing Stability: Pointing platform plus tip/tilt primary keeps image stable within the resolution element over the integration period
- Integration: ~ 4 s
- Sensitivity: 1000x current capability

EUVC Instrument Design



Mission Implementation



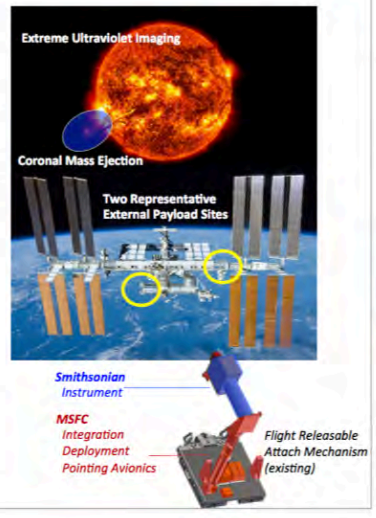
Solar viewing analysis for two representative ISS external site locations

Solar Viewing Capabilities at ISS Mounting Locations	Solar Viewing Opportunities (Days/Year)	Worst Case Solar Viewing Time per Orbit	Worst Case Solar Viewing Time per Day	Total Solar Viewing Time per Year
Columbus SOZ or ELC 3-3	365 days	28 min	7.2 hrs	2,640 hrs

Novel graded filter, prime focus imaging, high throughput, give the coronagraph unprecedented sensitivity: 1,000X current capability.

Additional scientific capability and value with overlap-o-gram channel.

- Slitless spectrometer disperses full solar image in spectral direction.
  - Compressed in λ direction for image separation.
- Heritage components.
- Less restrictions required for EUV versus white light coronagraph.
- No need for an occulter; not sensitive to dust or scattering, direct response to (CMEs).

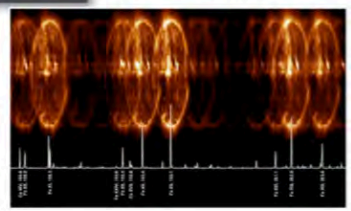


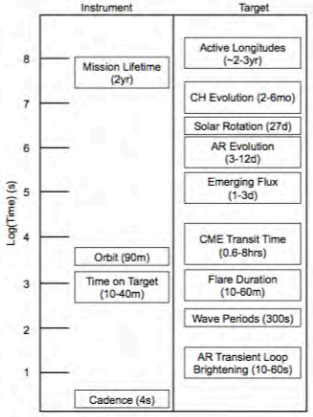
Mission Products

Spaceweather events and coronal magnetic connectivity are tracked through the corona:

EUV coronagraphs allow for visibility of both the source region *and* the propagating disturbance.

Spectral images provide plasma diagnostics (temperature, density and LOS velocity for fast flows ~100km/s).





(SAO | MSFC)

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IPM/ISE: Peter Cheimets

PM: Susan Spencer

Science Team:

Ed DeLuca (DPI)

Laurel Rachmeler (DPS)

Kelly Korreck, Kathy Reeves, Jenna Samra, Paola Testa, Mark Weber, Trae Winter, Jonathan Cirtain, Ken Kobayashi, Amy Winebarger

Hi-C 2 Status

- Beautiful flight, even after a week of delay
- Science images not captured due to the camera shutter not opening
- Loads of calibration images from the new MSFC camera design
- Achieved low noise requirements
- Anxious to refly